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Native versus Modern Almond Cultivars of Mallorca Island: From Biodiversity to Industrial Aptitude and Fruit Quality

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Abstract: Almond, one of the most characteristic crops in the agricultural landscape of Mallorca Island, cultivated mainly under rainfed conditions and from native cultivars, represents an important source of income for the Island. Nowadays, modern cultivars were introduced to meet the almond demand, agronomical needs, and climate change issues. Consumption has considerably increased in the last years and the SARS-CoV-2 virus contributed to consumer behavior changes. The present work aimed to characterize 14 cultivars of which 9 were modern and 5 natives. In general, the natives cultivars presented a lower weight (1.3 g), size (21 mm), darker skin (L = 38), softer texture (107 N), with more benzaldehyde flavor (2-fold change) and "twins" (16%), but with a greater thickness, fiber, and linoleic acid (0.1-fold change, respectively). Modern cultivars offered greater weight (1.5 g), size (24 mm), lighter skin (L = 39), and harder texture (121 N), with no or low benzaldehyde flavor and no "twins". Finally, 'Belona', 'Ferragnès', 'Marta', 'Masbovera', 'Penta', 'Soleta', 'Vairo', 'Duareta', 'Jordi' and 'Vivot' met all the requirements to be certified under the quality guarantee Protected Indication of Origin "*Almendra de Mallorca*". However, each cultivar presented its own profile which makes them suitable for different purposes in the food industry.

Keywords: autochthonous cultivars; breeding programs; "*Almendra de Mallorca*"; protected indication of origin standards; morphology; chemical composition; principal component analysis; agglomerative hierarchical clustering

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1. Introduction

United States of America (USA) is the largest producer of almonds, accounting for almost 78% of the world's production, followed by Australia (8%) and Spain (7%) [1]. Nonetheless, Spain, as well as Netherlands [1], was considered the largest consumer of almonds in 2020 with an average of 4.07 kg year^{-1} per capita, followed by South Korea, Australia, and USA (2.3, 2.3, and 2.2 kg year^{-1} per capita, respectively). The world almond estimated consumption (MT) is increasing yearly, an increment of 5, 11, 18, and 43% was observed from 2016 to 2020. The most remarkable increment was registered from 2019 to 2020 (25%), which matches the lockdown in most countries that occurred due to the SARS-CoV-2 virus (COVID-19) [2]. COVID-19 was first identified in Wuhan (China), and rapidly spread worldwide, leading World Health Organization to qualify the sprout as a pandemic in March 2020 [3]. To reduce the contact and slow the propagation of the virus lockdown was declared, and this led to important behavioral changes in food shopping and cooking, among others [4–6]. For instance, Spanish consumers as well as other European consumers increased their snacking consumption [4–6], a category that included sweets and nuts, which explains the high percentage of almond consumption in this period.

The Balearic Islands, the region where the present study was carried out, is considered an important Spanish region for almonds production with 24.032 ha in 2021, of which 23.702 ha are cultivated under rainfed conditions which explains the low yield (175 kg ha^{-1}) and production [7]. The almond has been considered one of the most characteristic trees in the agricultural landscape of Mallorca and Ibiza (Balearic Islands) cultivated mainly under rainfed conditions and from native cultivars [8]. Authors have mentioned about 100 native cultivars in Mallorca Island (hard shell: 'Pons', 'Canaleta', 'Pou de Felantix', 'Verdereta', 'Vivot', 'Jordi', 'Totsol', etc.; soft-semisoft shell: 'Poteta', 'Menut' etc.), which were previously mixed and commercialized as "*Mallorcas*" [9]. This represents a great diversity in terms of cultivated varieties and an important genetic wealth that should be maintained. However, it also represented a problem for the commercial sector, which was forced to present standardized and uniform products such as fewer varieties but well typified and classified [10]. Thus, the industry has chosen new cultivars from the Mediterranean breeding programs usually with late blooming and self-compatibility and those cultivars not productive according to commercial standards were ignored leading indirectly to biodiversity loss [11]. Breeding programs and so the improved cultivars are essential because they are agronomically more suitable for the farmers due to the late blooming, self-compatibility, and yield characteristics. However, the parents are continually drawn from the same genetic pool ('Cristomorto' × 'Tuono'), and this can lead to a potential loss of genetic variability in new breeding stocks and cultivars [11]. For this reason, modern and native cultivars are more cooperation than competition.

The almonds from Mallorca acquired a good reputation and commercial reception throughout history due to their organoleptic characteristics which translate to an important source of income for the island [12]. Most of it was exported to other Spanish regions (Alicante and Valencia) to produce sugared almonds and other sweets, while a significant amount of oil was also produced on the islands and shipped mainly to America [8]. Although, in the last years the cultivated surface has been significantly reduced and lower yields have been registered, this economic importance persists even now, since the cultivation of almonds in the Balearic Islands represents 39% of the area dedicated to the cultivation of tree fruit [13]. These economic gains led the producers and processors to show a great interest to maintain and set out new plantations and determined them to request for a quality label with the purpose of protecting the name and avoiding unfair competition [12]. Thus, since 2014, the Mallorca almonds are protected by the European Union under the name "*Almendra/Ametlla de Mallorca*" or "*Almendra/Ametlla Mallorquina*" Protected Geographical Indication (PGI) under the Council Regulation (EC) No 510/2006 [14]. This quality grant is offered when at least one of the stages of the production, processing or preparation takes place in a certain region and a specific quality is essentially attributable to its geographical origin [15]. In this sense this PGI underlines the link between the specific geographic region "Mallorca" and the name of the product "*Almendra/Ametlla*" (almond). This regulation establishes the requirements for the almond to which the name PGI "*Almendra de Mallorca*" applies and in general requires whole (chipped and broken with a maximum tolerance of 1% and 2%, respectively), healthy, clean, and dry almonds with a width greater than 12 mm at the widest point (allows a maximum tolerance of 5%) [14]. There must be no sign of fungal, parasite or insect damage, no rancidity, or any off-flavors. For the raw almonds a moisture, fat, and oleic and linoleic content of 6.5%, 55%, 88% is required. Regarding the organoleptic characteristics, the raw kernels are characterized by roughness and brown skin, while the blanched almonds should be white or ivory in color, with a mat appearance, both inside and outside. The taste should be slightly sweet, neither sour nor bitter, and an intense aroma of nutty notes. The texture should be firm, with little stickiness and an oily feel. Last, the regulation also specifies that almonds protected by the PGI "*Almendra de Mallorca*" must be grown, stored, hulled, peeled, and roasted on the island of Mallorca, because these physicochemical and organoleptic characteristics are conferred by the edaphoclimatic conditions of the geographical environment in which they are produced.

Overall, this explains the necessity of continuous technical and scientific data in the light of the current situation related to (i) Climate Change; (ii) the Green Deal whose objective is to make the EU's economy sustainable [16]; and Biodiversity Strategy whose goal is to protect the fragile planet natural resources, to restore the biodiversity and the well-functioning ecosystems [17]. In this context, the present study was focused on the evaluation of the morphological and physicochemical characteristics of modern and native cultivars to establish the industrial aptitude and the commercialization under de quality guarantee of PGI "*Almendra/Ametlla de Mallorca*".

2. Materials and Methods

2.1. Plant Material

A total of 14 cultivars were evaluated, of which nine were released by different Spanish breeding programs (modern) and 5 were native ('Desmeus', 'Duareta', 'Feliu', 'Jordi', 'Vivot') cultivars. All the samples were produced in Mallorca. Originally, the modern cultivars were released by three different Spanish breeding programs: four from IRTA ('Constantí', 'Marinada', 'Masbovera', and 'Vairo') [18–20], two from the "*Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA)*" ('Belona' and 'Soleta') [21], two from "*Centro de Edafología y Biología Aplicada del Segura*" (CEBAS-CSIC)" ('Marta' and 'Penta') [22,23] and one from "*Institut national de la recherche agronomique* (INRA)" ('Ferragnès') [24].

To understand if the genetic luggage can have some influence on the physicochemical characteristics of the modern cultivars a pedigree of them was developed in Figure 1. As observed 'Ferragnès' is the parental for the Marta and in the second generation for 'Constantí', 'Marinada', and 'Vairo'. 'Penta', also derives from 'Ferragnès', but in the third generation, and so there are many more cultivars involved. This aspect is important to check and determine if 'Ferragnès' may transmit any characters to the new generations. Moreover, 'Belona' and 'Soleta' could be also similar as they come from the same cultivar 'Blanquerna' crossed with 'Belle d'Aurons', cultivars that belong to different parents such as 'Genco' and 'Aï', respectively [21]. Finally,' Masbovera' was obtained from a cross between 'Cristomorto' and 'Primorskiy' [18,20].

2.2. Experimental Plot and Management

The experimental trial was conducted in 2020 in a commercial farm "Sa Tanca" located 140 m above sea level in Consell, Mallorca Island (UTM coordinates: 31N ETRS89: x = 484103, y = 4390160). The experimental plot has a total area of 1.5 ha planted with almond trees. The cultivars were sown on 2014 and grafted onto the same pattern (INRA GF-677), 6 m $\times$ 6 m spaced in a randomized block design and drip irrigated. All the cultivars received full irrigation (6000 m^3 ha^{-1} year) in addition to the pluviometry. The soil has a franco-clay texture, very calcareous, with the presence of coarse elements on the surface. The climatology is characterized by mild temperatures in winter and warm in summer, with an annual rainfall of 450–540 mm, mainly distributed from autumn to spring.

2.3. Physical Analyses of Kernels and Whole Almonds

2.3.1. Morphological Parameters

For the morphological parameters 45 individual almonds per cultivar were randomly selected and the kernels were measured (length, width, thickness) using a digital caliper (Mitutoyo 500-197-20, Kawasaki, Japan) and a scale (model AG204 Mettler Toledo, Barcelona, Spain) respectively.

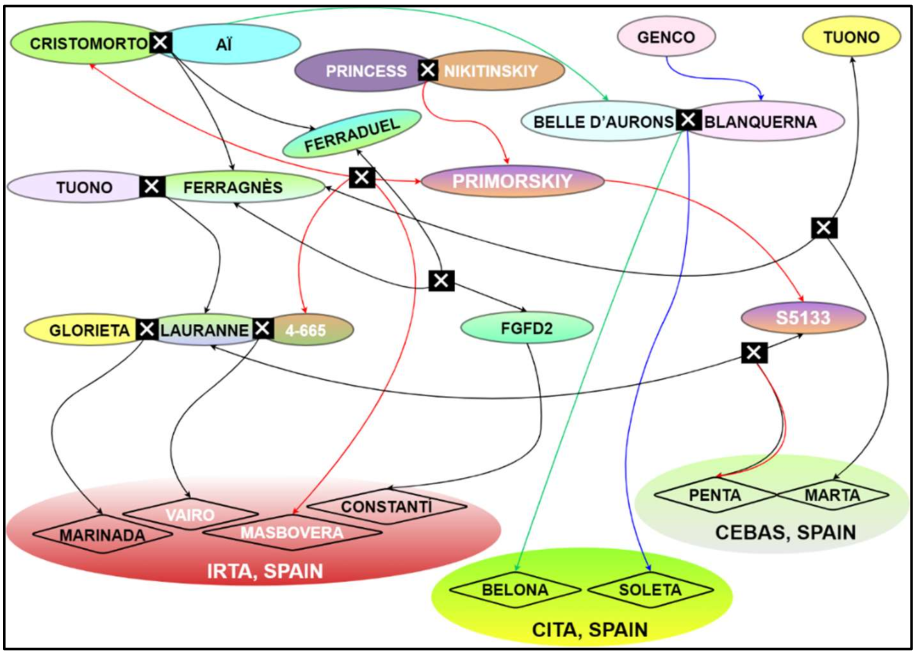

Figure 1. Pedigree of the nine modern almond cultivars analyzed in the present study. This figure must be read from the upper to down. Cultivars descendants of 'Cristomorto' × 'Aï' are linked using a black line, those from 'Princess' × 'Nikitinskiy' with a red line, those from 'Aï' with a green line and those from 'Genco' with a blue line. IRTA = Institute of Agrifood Research and Technology; CITA = Center for Research and Agrifood Technology of Aragon; and CEBAS = Center for Edaphology and Applied Biology of Segura.

2.3.2. Instrumental Color

Instrumental color was performed according to Lipan, et al. [25] with some modifications. The measurements were done at 23 ± 1 °C directly on the kernel skin using a MINOLTA CM-3500d colorimeter (Minolta, Osaka, Japan) having an 8 mm diameter viewing area. This spectrophotometer used a D_{65} illuminant and a 2° observer as references. Chromatic analyses were run following the International Commission on Illumination (CIE) system. Values of luminosity L^* (0 = completely opaque "black"; 100 = completely transparent "white"), red-greenish notes a^* (a^* = red; $-a^*$ = green) and yellow-bluish b^* notes (b^* = yellow; $-b^*$ = blue) were measured to describe a three-dimensional color space. The hue angle (°) which represents the color nuance was also calculated as follows: H ° = arctg (b^*/a^*), and values are defined as red-purple: 0°, yellow: 90°, bluish-green: 180°, and blue: 270° [26,27]. The data of each measurement represents the average of 45 kernels per cultivar measured on both sides of the kernel. To visually present the almond color for each cultivar an online color converter was used from L^*, a^*, b^*, color coordinates values [28].

2.3.3. Instrumental Texture

The instrumental texture was carried out on both in-shell and shelled almonds using an INSTRON texture analyzer model 3344 (Norwood, MA, USA). Forty-five almonds were measured running a compression test until breakage with a cylindrical probe 8 mm diameter descending at 1 mm s^{-1}. Strength (N), extension (mm), energy (N mm), and firmness (N mm^{-1}) were the 4 parameters analyzed within this research. Strength is the maximum force required to break the sample and is related to the limit of resistance of the material. The extension is the deformation of the sample before its breakage and is related to its elasticity. Energy is the area of the triangle formed by the line that draws the strength measured till breakage and the deformation of the sample and it is related to the total energy required to break the sample. Finally, firmness is the force required to produce a deformation of one millimeter in the sample and is related to the structure of the sample and its fragility during industrial processing [29].

2.4. Physicochemical Analyses of Blanched Kernels

2.4.1. Apparent and Real Density

Apparent and true density was determined according to Aydin [30], the former represents the ratio of the kernel mass to its total volume, while the latter is the ratio of the kernel mass to the solid volume occupied by the sample.

2.4.2. Weight Loss and Broken Pieces after Blanching Process

To determine the weight loss after the blanching process the skin and the broken pieces were weighted and the % of each part was calculated.

2.4.3. Moisture Content

The moisture content was measured by direct gravimetric determination using 2 g of ground almonds followed by oven drying at 103 °C to constant mass [31]. The dried sample was later cooled in a desiccator and weighed. The loss weight was calculated as the moisture content (MC) (1):

$$\mathrm{MC}\left(\%,\frac{\mathrm{w}}{\mathrm{w}}\right)=\frac{\text{weight loss on drying}}{\text{sample weight}}\times 100 \quad (1)$$

2.4.4. Proximate Analyses

Protein, fat, ash, and fiber content was carried out in triplicate following the official methods AOAC [31–33]. The nitrogen of 1 g of ground almond was determined with the Kjeldahl method by digesting UDK 127 (VELP Scientifica, Usmate Velate, Italy) the sample with sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH) and later converted to protein by multiplying a factor of 5.7 for vegetable material [32] using the following Equation (2):

$$\mathrm{P}\left(\%,\frac{\mathrm{w}}{\mathrm{w}}\right)=\frac{[\text{Volume of } H_2SO_4\ (\text{mL}) - \text{Volume of NaOH}\ (\text{mL})]\times 0.0014\times 100}{\text{sample weight (g)}}\times 5.7 \quad (2)$$

For fat content determination, 2 g of ground almond was subjected to extraction with diethyl ether for 1.5 h in Soxhlet equipment (Det-Gras J.P. Selecta S.A., Barcelona, Spain). Moreover, 0.5 g of ground almond and introduced in a muffle furnace model 12 PR/300 series 8B (Hobersal, Barcelona, Spain), set at 650 °C for 6 h were used to determine the ash content [33].

2.4.5. Oil Stability

The oxidative stability index of almond oils was determined using the Rancimat method according to ISO-6886 [34]. The equipment used was Rancimat 743 (Metrohm Co., Madrid, Spain), and the stability was expressed as the oxidative induction period (time necessary to achieve the inflection point of the conductivity curve) measured at 120 °C using 3 g of oil sample and an airflow of 20 L h^{-1}.

2.4.6. Fatty Acids

The fatty acids were converted to fatty acids methyl esters (FAMEs) before analyzing by mixing 40 mg of ground almond with dichloromethane (Cl_2CH_2) and methanolic NaOH for 10 min at 90 °C. Then, BF_3 methanolic was added and kept in a dark place for 30 min reaction followed by the extraction from the mixture with hexane [25]. The FAMEs separation was carried out in Shimadzu GC17A gas chromatography (Shimadzu Corporation, Kyoto, Japan) coupled with a flame ionization detector and a DB-23 capillary column (30 m length, 0.25 mm internal diameter, 0.25 µm film thickness) J&W Scientific, Agilent Technologies. The identification of methylated FAMEs peaks was done by comparing the retention times of the FAMEs Supelco MIX-37 standards. Results were expressed in % of total oil content as average values of three replicates.

2.5. Sensory Analysis of Kernels

Eight trained panelists (aged 25 to 55 years; 4 females and 4 males) belonging to the Institute of Agrifood Research and Technology (IRTA) participated in this study. The panel was selected and trained following the ISO standard 8586-1. For the present study, the panel worked during 3 orientation sessions (2 h for each one) discussing the main organoleptic characteristics of almonds using the lexicon previously published by Lipan, et al. [35]. Samples were assessed using sensory attributes regarding basic tastes and somatic sensations as well as flavor and texture. References were chosen and prepared according to above mentioned lexicon using similar attributes, and then provided to panelists. The used scale ranged from 0 (no intensity) to 10 (extremely high intensity) with 0.5 increments.

2.6. Statistical Analysis

Data was analyzed by applying the one-way analysis of variance (ANOVA) followed by Tukey's HSD (honestly significant difference) multiple range tests to check statistical differences among samples for morphological and physicochemical parameters. The statistical model was:

$$\text{Variable} = \text{origin} + \text{cultivar (origin)} + \text{tree (cultivar)} + \text{error} \quad (3)$$

in which the term "origin" refers to the type of cultivars, whether modern or native. For the variables "crease" and "twins" the Chi-square statistic non-parametric test has been used. Significant differences were considered when $p < 0.05$. Principal component analysis (PCA regression map) after Varimax rotation was conducted to project the samples considering only those significant parameters that were considered to have an impact on the almond characterization. Finally, an Agglomerative Hierarchical Clustering (AHC), using Euclidean distance and Ward's criterion of aggregation was used to group similar almond cultivars into clusters. Both PCA and HCA were applied to standardized data before conducting the analyses, in this sense each variable received equal weight in the analysis. All the statistical analyses were performed using XLSTAT Premium 2016 (Addinsoft Inc., New York, NY, USA).

3. Results and Discussion

3.1. Cultivar Effect on Weight, Size, and Shape

Morphological parameters, as well as color and texture are of utmost importance for the food industry to determine the final processing. For instance, vegetable milk industry would look for cultivars with a blanched seed color as white as possible, with chocolate industry would need almonds with a uniform shape and size due to the maximum chocolate tablet thickness, while for slices and sticks uniform kernels with a significant length are needed to obtain uniform products [36]. Table 1 presents the results of these parameters for each cultivar but also by clustering them in only 2 groups, one for all modern cultivars and one for the native ones. As seen, 'Belona' followed by 'Ferragnès', 'Marinada' and 'Masbovera' registered the greatest weight (1.73, 1.59, 1.54, and 1.52 g, respectively) while the opposite was observed for 'Desmeus', 'Jordi', 'Duareta', 'Penta', and 'Vivot' (1.10, 1.20, 1.22, 1.24, and 1.36 g, respectively). Knowing that the chocolate industry requires almonds with a weight of ~1.0 g [36], 'Desmeus', 'Jordi', 'Duareta' and 'Penta' might be the best options. Regarding the length, 'Ferragnès' (26.8 mm) and 'Soleta' (26.2 mm) registered the highest values, while 'Duareta' (19.5 mm) and 'Desmeus' (20.1 mm) the lowest ones. The greatest width was observed again in 'Belona' (17.3 mm) and the lowest in 'Penta', 'Vivot', and 'Desmeus' (12.7, 12.9, 13.1 mm, respectively). As seen, heavier almond cultivars are also larger and wider, but not thicker, because a positive correlation was observed between weight with length (r = 0.72; $p < 0.0001$) and width (r = 0.74; $p < 0.0001$) but not with thickness (r = 0.005; $p > 0.05$). The latter, was even higher for the native cultivars, being 'Duareta' (9.38 mm) and 'Feliu' (9.02 mm) the thickest cultivars and the opposite was observed for 'Belona' (7.88 mm), and 'Soleta' (7.28 mm). The thickness is an important parameter for the chocolate industry, for instance chocolate coated almonds require thick almonds which contribute to the shape of the bonbon or praline [37]. Furthermore, thickness improves the aspect of the almonds in snacks and toasted cocktails. The length:width ratio was calculated to assess the almond shape, as observed 'Ferragnès', 'Marta', 'Soleta', and 'Vivot' (1.85 in average) were the samples with the highest values, and the contrary was observed for 'Belona', 'Constantí', 'Duareta' (1.43 average). These values are in agreement with Romero [36] although slightly higher values were reported by the author (1.93 and 1.46 average) mainly for the cultivars with the biggest shape. These small differences might be related to the location, as the reported study was carried out in the Peninsula (Spain) and the present one in the Island (Spain). Regarding weight and size, it can be stated that the breeders were looking for good size because the modern cultivars presented a greater weight (1.47 g) and size (24.4 mm) than the native ones (1.26 g and 21.5 mm, respectively) although, the thickness was lower [38]. In this way, all modern cultivars presented a width higher than 12 mm and met the specification of the "*Almendra/Ametlla de Mallorca*" regulations related to size.

In general, the morphological results presented a great variability among samples showing that each cultivar has its characteristics and mixing them, as it is done usually under the commercial designation "comuna", might influence the processing later. For instance, it is well known that samples as similar as possible in size are needed to avoid dissimilarities after the roasting process [39], as well as, that almonds different in sizes and shapes might be used for different industrial purposes because some industrial properties depend on those specifications. However, in Spain, the almond classification was generally divided into 3 main types (Marcona, Largueta and Comuna, the latter being a mix of undefined varieties) [40]. By 2020, the almond sector counts on a new classification divided into 5 types: (i) Lauranne type ('Lauranne', 'Ferragnès', 'Penta' and 'Marta'), (ii) Guara type ('Guara', 'Marinada', 'Constantí' and 'Vairo'), (iii) Marcona type ('Marcona', 'Belona' and 'Antoñeta'), (iv) Largueta type ('Largueta' and 'Soleta'), and (v) Valencia type (including native and late blooming cultivars) [41]. Regarding the present study 'Ferragnès', 'Marta' and 'Penta' are only similar in thickness and the first 2 cultivars in shape (length:width ratio). From the 2nd type 'Constantí', 'Marinada' and 'Vairo' are all of them similar in width, the first 2 cultivars in thickness and the last 2 in weight and shape.

Finally, morphological results were also compared with the pedigree of the modern cultivars presented in Figure 1 to check if the genetics were transferred to the progenitors and as seen 'Marta' is a cross between 'Ferragnès' and 'Tuono', that could explain the similarities in shape between these 2 cultivars, as well as for 'Marinada' and 'Vairo' that belong to 'Lauranne' crossed with different cultivars.

Table 1. Morphology, instrumental color, and texture of 14 almond cultivars (9 modern and 5 native cultivars).

	KERNEL															SHELL				
	Morphological Parameters and Defects							Color Coordinates				Instrumental Texture				Morphological and Instrumental Texture				
	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	Length:Width Ratio	Creasy (%)	Twins (%)	*L**	*a**	*b**	Hue (°)	Strength (N)	Extension (mm)	Energy (N mm)	Firmness (N mm^{-1})	Thickness (mm)	Hardness Shell (N)	Extension (mm)	Energy (N mm)	Firmness (N mm^{-1})
R^2 (explained variability) and ANOVA test †																				
R^2	0.57	0.74	0.72	0.47	0.8	Chi-Square		0.29	0.32	0.41	0.45	0.25	0.27	0.21	0.35	0.59	0.61	0.44	0.48	0.75
Individual cultivars (cv)	***	***	***	***	***	χ^2 = 321 ***	χ^2 = 241 ***	***	***	***	***	***	***	***	***	***	***	***	***	***
Modern vs. Native cv.	***	***	**	***	**	χ^2 = 0.36 NS	χ^2 = 70.7 ***	***	NS	*	***	***	**	***	***	***	***	***	***	***
Tukey's Multiple Range test ‡																				
Belona	1.73a	25.0b	17.3a	7.88f	1.45d	0.00d	0.00b	39.5b	16.3a	28.6b	60.1b	133a	1.50e	102c	88.8a	3.81b	507d	2.08b	546d	252c
Constantí	1.36d	21.9e	15.5b	8.77b	1.41d	0.00d	0.00b	36.9d	14.0c	23.0e	58.5d	119c	1.81b	109b	65.8d	4.20a	724a	2.62a	963a	281c
Ferragnès	1.59b	26.8a	14.6c	8.13c	1.84a	82.2a	0.00b	39.4b	15.2ab	25.5d	59.1c	126b	1.82b	115b	70.2c	3.36c	313f	1.94c	314f	162d
Marinada	1.54b	23.6d	15.6b	8.86b	1.52c	8.89b	0.00b	39.2b	15.2b	26.4c	59.9b	124b	2.00a	125a	62.7d	3.72b	197i	2.76a	281g	73e
Marta	1.43c	24.8bc	13.4fg	8.42c	1.86a	11.1b	0.00b	36.6d	15.6ab	24.6d	57.3e	108d	1.94a	106	56.5e	3.36c	550d	2.13b	591c	262c
Masbovera	1.52b	25.2b	14.5cd	8.26c	1.75b	17.8b	0.00b	37.8c	14.6b	23.7e	58.2d	135a	1.79c	122a	77.4b	3.78b	384e	2.17b	463d	177d
Penta	1.24e	22.1e	12.7h	8.50c	1.75b	2.22c	0.00b	41.9a	16.3a	29.9a	61.3a	106d	1.80b	96.6d	60.3d	2.92e	521d	1.51f	401e	354b
Soleta	1.42c	26.2a	14.0de	7.28d	1.88a	2.22c	0.00b	40.6a	15.5ab	28.0b	60.9a	136a	1.65d	113b	84.6a	3.23c	242g	1.89c	222h	143d
Vairo	1.36d	23.9cd	15.3b	8.16c	1.56c	11.1b	0.00b	39.1b	13.9c	24.3d	59.8b	106d	1.78c	95.9d	59.8d	3.47c	480e	1.98c	484d	245c
Desmeus	1.10f	20.1f	13.1fgh	8.49c	1.54c	11.1b	0.00b	39.6b	15.9a	30.7a	62.6a	103d	1.76c	91.5d	59.0d	3.10d	602c	1.76d	533d	351b
Duareta	1.22e	19.5f	13.6ef	9.38a	1.44d	0.00d	46.7a	36.5d	15.1b	25.5d	59.2c	119c	1.94a	117b	62.5d	3.05d	616b	1.91c	608c	329b
Feliu	1.44c	21.9e	14.4cd	9.02a	1.52c	73.3a	0.00b	36.9d	13.4c	24.4d	61.1a	119c	1.70d	102c	70.6c	3.75b	755a	1.89c	744b	412a
Jordi	1.20e	22.4e	13.0gh	8.21c	1.73b	0.00d	35.6a	37.8c	16.5a	28.9b	60.2b	97.8e	1.55f	77.3e	63.8d	2.48f	542d	1.52f	428e	361b
Vivot	1.36e	23.8d	12.9gh	8.71b	1.84a	0.00d	0.00b	37.7c	13.9c	24.3d	60.2b	96.4e	1.61d	79.5e	60.6d	2.80e	584c	1.65e	488d	363b
Modern vs. Native cultivars																				
Modern	1.47a	24.4a	14.7a	8.25b	1.67a	15.1	0.00b	39.0a	15.2	26.0b	59.5b	121a	1.79a	109a	69.6a	3.54a	435b	2.12a	474b	216b
Native	1.26b	21.5b	13.4b	8.76a	1.61b	38.4	16.4a	37.7b	14.9	26.8a	60.6a	107b	1.71b	93.5b	63.3b	3.04b	620a	1.74b	560a	363a

† NS = not significant at $p > 0.05$; *, **, and *** significant at $p < 0.05$, 0.01, and 0.001, respectively. ‡ Values (means of 45 replications per cultivar) followed by the same letter within the same column and factor were not significantly different ($p < 0.05$), according to Tukey.

3.2. Cultivar Effect on Instrumental Color, and Texture

Instrumental color has also been measured on the almond skin and the statistical differences among samples are presented in Table 1. The luminosity (L^*) values ranged from 36 to 42, being 'Constanti', 'Marta', 'Duareta', and 'Feliu' the cultivars with the lower values (L^* = 36.9, 36.6, 36.5, and 36.9, respectively) which mean the darkest skin, while 'Penta' (L^*= 41.9) and 'Soleta' (L^* = 40.6) presented the lightest one. 'Belona', 'Penta', 'Jordi', and 'Desmeus', presented the highest values of a^* (a^* = 16.3, 16.3, 16.5, and 15.9, respectively) and b^* (b^* = 28.6, 29.9, 30.7, and 28.9, respectively) color coordinates, a synonym of reddish and yellowish almonds. For easier visualization of these values, the pantone of each cultivar was obtained using an online color converter and the results are presented in Figure 2. Although the visual differences are minimal, it can be highlighted that the samples listed above with low values of L^*, b^*, and Hue were visually darker 'Constanti', 'Marta', 'Duareta', and 'Feliu', and the others with higher values of L^*, b^* and Hue were lighter ('Penta', 'Soleta', 'Belona', 'Ferragnès, 'Marinada', and 'Desmeus'. These differences are normal because each almond cultivar has a unique polyphenol profile that significantly contributes to the almond skin color due to flavonoids role in yellow pigmentation, and to high-molecular-weight fraction (proanthocyanidins) in brown pigmentation [42,43]. It is well known that color is among the most decisive element that consumers use to distinguish product quality, because is usually the first sensory attribute to hit the senses [44]. However, almond regulations do not specify kernel color as a tool to distinguish the varietal character. Consumer attitude to nuts consumption has changed what led to a significant increase in nut consumption as a snack. Because of that, besides offering almonds for confectionary purposes, the almond industry might fulfill the new market segment of raw almond consumers, that demand this format. For this type of commercialization, skin color is essential, and the almond providers started to lean their efforts toward attractive cultivars and appropriate conservation. It was reported that the almond skin color tends to get darker as a result of oxidative rancidity, changes in phenolic compounds and antioxidant fraction [45]. Considering that consumer preference plays a key role in determining the marketability of foods, almonds unusually dark might be perceived as rancid or not fresh leading to rejection and so economic losses.

On the other hand, texture analysis was carried out both in kernels and in-shell almonds and the results are presented in Table 1. The kernel strength ranged from 98 to 136 N being 'Belona', 'Masbovera' and 'Soleta' the hardest almonds, while 'Jordi' and 'Vivot', were the softest ones. It must be highlighted that 'Belona' and 'Soleta' belong to the same parentals (Figure 1) that might have transmitted to progeny the same strength. Moreover, it can be highlighted that size and rupture force presented a significant relationship ($p < 0.001$), showing that hard almonds are usually characterized by a greater size. These results are also stated by other authors [30,46,47]. Regarding consumer acceptance of raw kernels, averages of about 70 N for the firmness were well accepted by the consumers [25,35,47]. Thus, higher, or lower values than these might have a negative impact on consumer acceptance that should be studied in further research.

A huge variability was found for the texture of in-shell almonds ranging from 197 to 724 N of strength. 'Feliu' together with 'Constantí' was the cultivar with the hardest shell and the opposite was observed for 'Marinada'. These parameters are of utmost importance in the cracking operation because determining the efficacy of the first processing step that is the kernel separation important to avoid kernel damage [48]. In general, it can be said, that native cultivars despite having a harder shell than the modern cultivars (620 N compared to 435 N), presented softer kernels (107 N compared to 121 N). This means that the cracking operation would require more force, while the industry might be more careful to avoid kernel breakage. Moreover, it is worth mentioning that shell thickness presented higher values for the modern cultivars compared with the natives, the shell strength was lower. This might occur due to a different endocarp structure with bigger empty space [49].

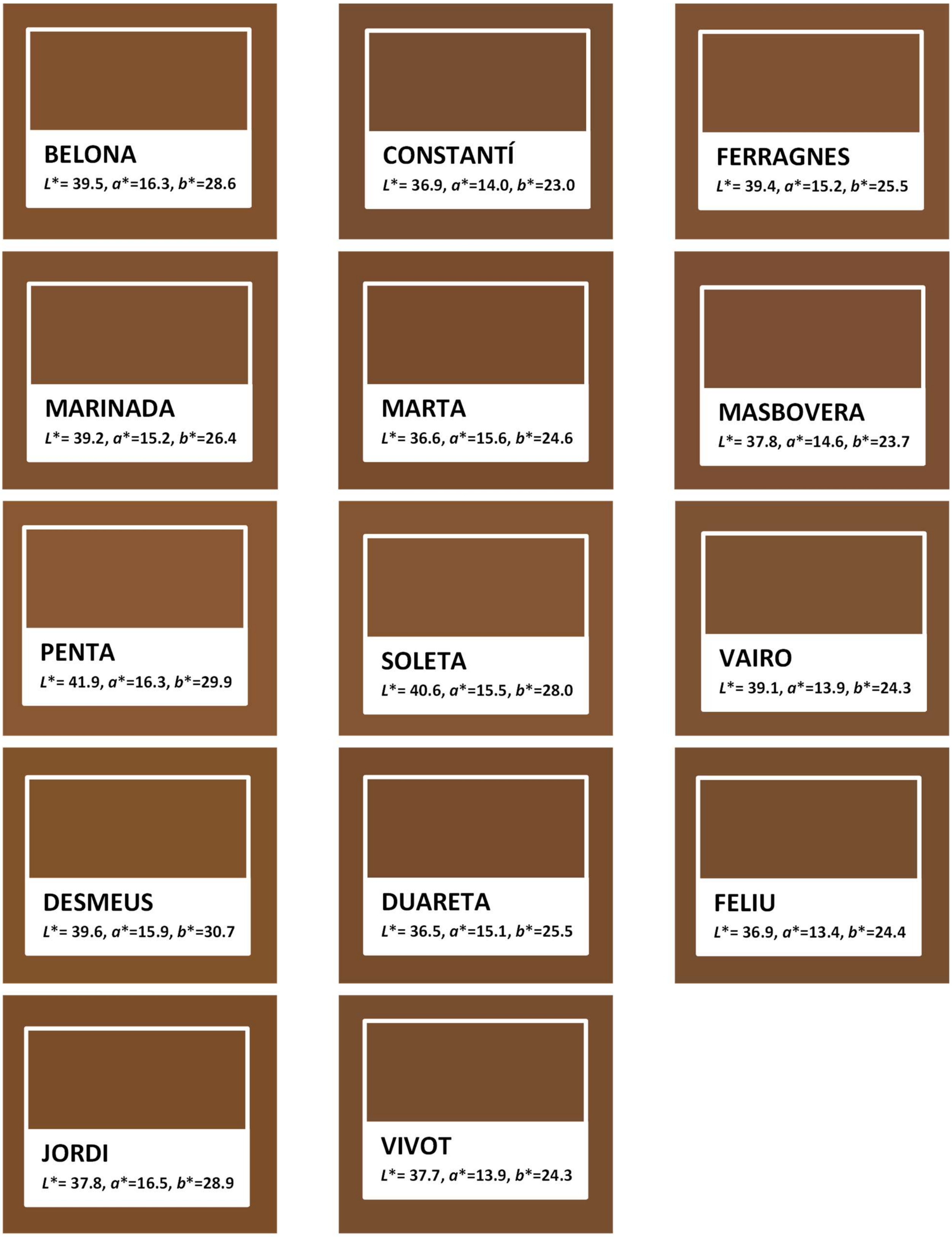

Figure 2. Pantone of each cultivar combining L^*, a^*, b^* color coordinates values in a color converter.

3.3. Cultivar Effect on Defects

"Creasy" and "twins" or "doubles" are two important defects that affect the grading for almonds, regardless of the cultivar or size. The former is represented by the presence of depression on one side of the kernel which is cultivar dependent and implies a problem for the industry that needs uniform shapes, for instance to obtain high-quality slices [36,50]. While the latter is characterized by two kernels developed in one shell which make one side of a double kernel flat or concave. The United States Department of Agriculture (USDA) establishes the regulations for the almond's grades permits only 3% and 5% of "twins" for the first two grades (U.S. Fancy and U.S. Extra No. 1.) increasing to 15% for the other two levels [51]. In Spain the "twins" tolerances are 5% for the grades Extra and Supreme, 10% for Selected Valencias, 20% for Unselected Valencias and 35% for Whole and broken [41]. The PGI "*Almendra/Ametlla de Mallorca*" regulations have no specifications about these defects. The "twins" defect is cultivar dependent and appears due to the development and fertilization of two ovules in the ovary [50]. Although almond taste is not affected, this defect is critical in almond processing, mainly in cracking, blanching and slicing operations [36,50] and makes it a critical point in the classification of the almonds by quality grades. In this context, the results of the present research showed that cultivars such as 'Belona', 'Constantí', 'Duareta', 'Jordi', and 'Vivot' are free of "crease" defects, that mainly appeared in 'Ferragnès' (82%) and 'Feliu' (73%). It was reported that the crease defect has a significant heritability [50] which can also be confirmed by these results (Figure 1) because most of the cultivars having this defect originated from 'Ferragnès', except for 'Masbovera' that belongs to different parental (Cristomorto × Primorskiy). As seen, this defect appeared both in modern and native almond cultivars, with no significant differences between both groups. Regarding the double kernels, only appeared in two native cultivars ('Duareta' and 'Jordi' with 47% and 36%, respectively), exceeding the thresholds established for the last grades by USDA and Spain. On the other hand, the modern cultivars were free of "twins", which shows how the breeding programs were able to eliminate this defect in the modern cultivars by using parents with very low doubling to minimize the problem in the progeny [38,50].

3.4. Cultivar Effect on the Kernel Physical Properties after Blanching Process

Blanching operation using steam has many functions such as (i) pasteurization, because reduce the microbial load in naturally contaminated almonds and the risk of disease from pathogens [52,53]; (ii) elimination of the hydrocyanic acid caused by the presence of wild almonds through hydrolysis [40]; and (iii) separation of the seed tegument (skin). The latter is the main purpose of blanching operation and is widely used by the industry in confectionery, almond milk, ice cream, snack, flour, cereals, etc. This operation consists of soaking the kernels in hot water (about 90 °C) for at least 2 min which facilitates the seed coat removal done by two rubbing strengths working in opposite directions at different speeds [40]. Later the moistened skin is removed by an air stream. As observed, this operation consists of many steps in which the almonds suffer numerous impacts, thus its success is achieved when the percentage of losses (broken kernels) is low, and the kernels are completely white without any skin residue. For this reason, in the present study the broken kernels after blanching and the skin percentage were also measured as well as the apparent and real density important for storage and transportation.

As seen, the weight loss after the blanching operation ranged from 7 to 10%, with 'Constantí' having the lowest skin percentage and 'Duareta' de highest one. Regarding the broken samples after the blanching operation there was great variability among samples which ranged from 3 to 16%. The samples with the lowest percentage of broken parts were 'Duareta' (3%), 'Belona' (4%), 'Vairo' (4%), 'Ferragnès' (6%), 'Penta'(7%) and 'Feliu' (7%), while the most affected was 'Jordi' (16%). These two parameters were dependent on the cultivar but not on modern or native type, as no significant differences were found among samples. As seen, 'Jordi' (96 N) and 'Vivot' (97 N) presented the lowest strength and also the greatest broken damage. However, this trend does not happen in all cultivars which explains the low correlation observed between these parameters.

The apparent and real density registered a mean value of 0.53 and 0.97 g cm^{-3}, respectively, and these results are in agreement with those reported by Aydin [30] in the

Turkish cultivar 'Taşbadem'. It must be highlighted that these authors observed a strong positive correlation between moisture content and real density (R^2 = 0.97), and a negative correlation between moisture and an apparent density (R^2 = 0.97) for both kernels and in-shell almonds. Thus, almonds with higher moisture content would have a higher real density and a lower apparent density. This could not be the case in the present study, since all the samples were dried at the same final moisture, meaning that differences in density must be related to some traits of the cultivars. In fact, PCA analysis shows an opposite relationship between apparent density and kernel length which can explain the higher empty space among kernels in the pile. Regarding this, the native cultivars registered a slightly higher apparent density, whereas any significant differences were observed for real density meaning a very similar inner kernel structure for all the cultivars studied.

3.5. Cultivar Effect on Nutritional Components

Protein, moisture, fat, sugar, fiber, and ash content were measured to determine the nutritional composition of each cultivar and the results are presented in Table 2. Protein and fat content ranged between 26.4 to 32.6% and 49.9 to 58.6%, respectively, being 'Belona', 'Vivot', 'Masbovera', and 'Penta' the cultivars with the lowest amount of protein (26.4, 26.6, 27.0, and 27.0%) and highest amount of fat ('Belona' 58.5% and 'Vivot' 58.6%), on the contrary 'Constantí' and 'Desmeus' registered the highest values of protein (31.3 and 32.6%) and the lowest of fat (54.9 and 49.9%). High variability was found among samples in terms of these nutritional compounds and a strong negative and significant correlation (r = −0.87; $p < 0.0001$) was found between them. As expected, samples with a high amount of protein contained a lower amount of fat and vice versa. The ratio between fat and protein is highly important in processing because the absorption of water by almond paste will depend on the balance between them [54]. Regarding this, cultivars such as 'Belona' (2.21), 'Vivot' (2.20), Masbovera' (2.08), 'Penta' (2.06), 'Jordi' (2.00), are more suitable for "*Turrón*" processing because high indices are needed, while 'Desmeus' (1.53) or 'Constanti' (1.66), are more indicated for marzipan production due to the low value of fat:protein ratio. The fat content is regulated by the PGI "*Almendra/Ametlla de Mallorca*" and this quality guarantee only accepts almonds with a total fat content in a dry weight basis ≥ 55%. Thus, cultivars such as 'Constanti', 'Marinada', 'Desmeus', and 'Feliu', do not meet this requirement due to a lower amount of fat than required by this PGI. These results might be confirmed in the following growing cycles to exclude the external climate factors effect. In terms of fatty acids, the sum of oleic and linoleic acids of all samples was higher than 90% (Figure 3), with this gathering the requirements established by the PGI regulation (≥88% of total lipids). The oleic acid content was similar among samples with a mean value of 75%, while linoleic acid ranged between 12% for 'Feliu', 'Desmeus', 'Masbovera' and 'Penta' and 22% for 'Duareta', 'Jordi', and 'Vivot'. It must be highlighted that higher linoleic acid increases the healthy properties but also reduce the product stability, and this is important information to decide the product shelf life and destination.

Regarding sugars, the cultivars with the lowest content (1.02%) were 'Constantí', 'Ferragnès', 'Marinada' whereas 'Marta', 'Soleta', and 'Masbovera' showed the highest values (3.81%). Crude fiber content was also measured, and the results ranged from 7.64 to 15.0%, with 'Feliu' (7.64%), 'Desmeus' (8.56%), and 'Marinada' (8.75%), having the lowest content, while 'Duareta' (15%), followed by 'Jordi' (13.4%) and 'Vairo' (12.2%) registered the highest values of fiber. Finally, oil stability analysis revealed that 'Jordi', 'Ferragnès', 'Marinada' and, 'Soleta' were characterized by a low stability (4 h), while 'Contanti', 'Desmeus' or 'Penta' were two times more stable (8 h) in the accelerated aging test. A strong positive correlation was found between oil stability and oleic acid (R^2 = 0.84; $p < 0.001$) and a negative relationship was found for oil stability and linoleic acid (R^2 = 0.87; $p < 0.001$). Regarding the relationship between native and foreign nutritional composition, significant differences were observed for fat and protein, because 'Desmeus' is very low in fat content and very high in protein. In addition, all the native cultivars show an ash content higher than 3.1% whereas the foreign cultivars cover a wider range. Furthermore, the foreign cultivars show a fiber content of 7–12% whereas the native include two cultivars over 12%. Finally, the foreign cultivars have a stability range of 5–9 h like most of the natives cultivars, but 'Duareta' and 'Jordi' are lower than 5 h. This means that the chemical composition is cultivar dependent, and there are native and modern cultivars high and low in fat, protein, sugar, fiber, and stability. Furthermore, the kernel composition was not a breeding goal so far.

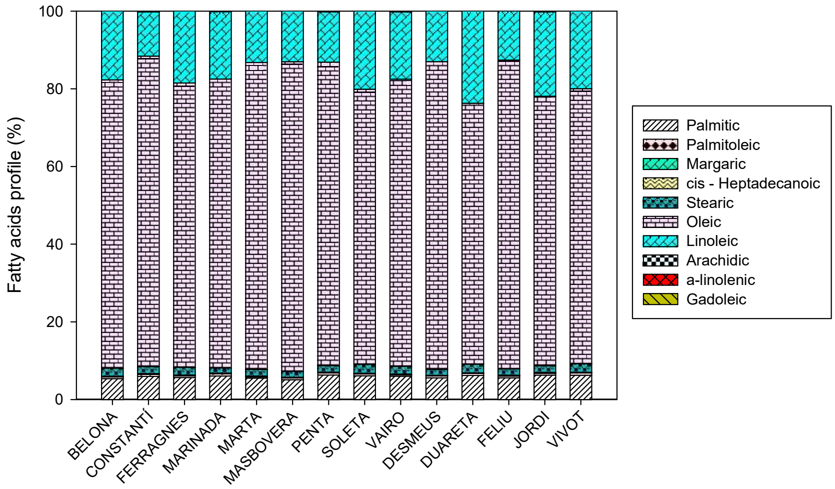

Figure 3. Fatty acids profile (expressed in % of total oil content) of each almond cultivar.

All these parameters make almonds to be the basic ingredient in the Mediterranean diet due to high nutritional value contributing to a healthy lifestyle. The epidemiological studies and clinical trials carried out so far have reported positive effects regarding the consumption of almonds against cardiovascular diseases, obesity, hypertension, diabetes, etc., associated with nutrients and phytochemicals [55–57]. On the other hand, the chemical composition is a key factor for the industry because influences completely its application. For instance, Spanish regulations for PGI "*Turrón de Alicante*" (hard texture) requires a minimum of 46 and 60% of almond in extra and supreme quality, respectively, while in PGI "*Turrón de Jijona*" (soft texture) a minimum of 50 and 64% is required to obtain products with a composition of 11–12% protein and 32–36% fat content [58]. A lower oil content will significantly influence the texture and its nutritional value, while a higher content will increase the oil migration risk with a negative influence on consumer preference [36,59]. A higher fiber content might lead to a hard texture in "*Turrón de Jijona*" which is expected to be smooth and soft [36,59]. On the other hand, the chocolate industry requires for low fat almonds otherwise combined with the high fat content of cocoa butter triggers the calories. Finally, for an easier milling process and correct flow properties of flour, almonds not rich in complex sugars and fat are required [36]. Considering all these specifications it can be said that all cultivars are suitable for "*Turrón*" production, except for 'Desmeus', and 'Constantí' due to the low amount of oil. However, these cultivars with a low percentage of fat could work better for almond flour or for protein bars due to their correlated high protein content. However, these cultivars with low fat content could match the almond milk industry, to reach the caloric level of cow's milk, as well as for chocolate industry where a lower amount of fat is needed to obtain a lower total caloric as possible [36,54,60]. 'Duareta', 'Jordi', and 'Vairo' are not indicated for soft texture confectionery because a negative correlation was reported between fiber and texture [37], however in terms of health properties these cultivars contribute with a highest amount of fiber, though raw almonds should be the best for this purpose. It was reported that the consumption of raw as well as roasted almonds might be associated with a lower risk of colon cancer and gut disorders in general, also related to almond high-fiber content with positive effects on the digestion and intestinal microbiota [61,62].

Table 2. Physicochemical parameters measured after blanching process of 14 almond cultivars (9 modern and 5 native cultivars).

	Apparent Density (g cm^3)	Real Density (g cm^3)	Skin Part (%)	Brocken Blanched (%)	Moisture (%)	Protein (%)	Fat (%)	Fat: Protein Ratio	Sugar (%)	Fiber (%)	Ash (%)	Stability (h)
					R^2 ANOVA test †							
R^2	0.72	0.28	0.57	0.66	0.95	0.98	0.99	0.99	0.99	0.83	0.99	0.996
Individual cv.	***	NS	**	**	***	***	***	***	***	***	***	***
Modern vs. Native cv.	*	NS	NS	NS	***	***	***	***	***	***	***	***
					Tukey´s Multiple Range test ‡							
					Individual cultivars							
Belona	0.51c	0.98	9.08b	4.18c	6.61d	26.4e	58.5a	2.21a	1.60f	10.4c	3.22d	5.82e
Constantí	0.53b	0.96	7.02c	9.71b	7.34a	31.3b	51.9g	1.66h	1.02h	10.8c	3.60a	8.09a
Ferragnès	0.51c	0.97	9.32b	6.07c	7.05b	28.1d	56.1c	1.99c	1.02h	9.63d	3.61a	5.45f
Marinada	0.53b	0.96	9.24b	10.0b	7.08b	29.3c	54.6e	1.86f	1.07h	8.75e	3.64a	5.33f
Marta	0.52b	0.96	9.39b	7.62b	7.02b	28.8d	55.2d	1.91e	3.81a	9.72d	3.35c	7.08bc
Masbovera	0.53b	0.96	8.09b	12.2b	6.93c	27.0e	56.0c	2.08b	2.99b	9.15d	3.50b	7.01bc
Penta	0.54ab	0.97	8.44b	6.59c	6.89c	27.0e	55.6d	2.06b	1.90d	10.3c	3.53b	7.29b
Soleta	0.51c	0.96	9.81a	8.85b	7.18a	29.9c	55.6d	1.86f	3.27b	9.91c	2.15e	5.23f
Vairo	0.52b	0.95	9.09b	4.16c	6.92c	28.2d	55.7d	1.98d	1.69e	12.2b	3.31d	6.07d
Desmeus	0.55a	1.00	8.96b	11.8b	7.20a	32.6a	49.9h	1.53i	1.75d	8.56e	3.48b	7.75a
Duareta	0.55a	0.96	10.0a	3.21c	6.92c	29.2c	56.5c	1.94d	1.32g	15.0a	3.46b	4.89g
Feliu	0.52b	0.97	8.86b	6.83c	7.11b	29.7c	53.3f	1.79g	2.04c	7.64e	3.70a	6.80c
Jordi	0.53b	0.95	9.36b	16.0a	6.89c	28.5d	57.1b	2.00c	1.31g	13.4ab	3.64a	4.31h
Vivot	0.52b	0.96	8.17b	10.7b	6.54d	26.6e	58.6a	2.20a	1.61f	10.7c	3.39c	5.59e
					Modern vs. Native cultivars							
Modern	0.52b	0.96	8.83	7.71	6.93b	27.3a	51.3b	1.89b	1.49b	10.3a	3.28a	5.86b
Native	0.53a	0.97	9.07	9.72	7.00a	26.5b	51.6a	1.96a	1.90a	9.39b	3.19b	6.37a

† NS = not significant at $p < 0.05$; *, **, and ***, significant at $p < 0.05$, 0.01, and 0.001, respectively. ‡ Values (means of 3 replications) followed by the same letter within the same column and factor were not significantly different ($p < 0.05$), according to Tukey's.

3.6. Descriptive Sensory Profile

A panel of nine trained panelists was used to evaluate the sensory characteristics of the present cultivars and the results of each sensory profile are presented in Figure 4. In general, the almond cultivars were similar in flavor, and the most important parameter that made the difference among the samples was the benzaldehyde flavor. This volatile compound is a breakdown product of amygdalin (cyanogenic glycoside naturally generated in almond) and so the predominant volatile compound mainly in bitter almond. A content of 12.1 mg kg^{-1} of benzaldehyde was reported in wild ("bitter") almond (*Amygdalus scoparia*) compared to 0.06 mg kg^{-1} reported in sweet almonds [*Prunus dulcis* (Miller) D. A. Webb syn. *P. amygdalus* (L) Batsch] cultivar 'Vairo', this huge variation is because of the low content of amygdalin, the benzaldehyde precursor, in sweet almonds [63–65]. The panelists detected an intense benzaldehyde flavor in 'Duareta' (2.7), 'Desmeus' (2.3), 'Marta' (2.0), and 'Vivot' (1.5), and a very low level in 'Soleta' (0.01), 'Vairo' (0.01), Penta (0.3), 'Ferragnès' (0.3), and 'Marinada' (0.3) in a 0 to 10 scale. Overall, it can be seen (Figure 5) that native almonds are more susceptible to develop this volatile compound compared to the modern cultivars, which explains the efforts done by the breeding programs to reduce the benzaldehyde intensity. "Bitterness" or benzaldehyde flavor in an almond was attributed to recessive allele of the *Sweet kernel* (Sk/sk) gene and is selected against in breeding programs [38,66], that is why the modern cultivars presented lower intensity of benzaldehyde.

3.7. Principal Component Analysis (PCA) after Varimax Rotation and Agglomerative Hierarchical Clustering (AHC) on Physicochemical Parameters of Kernel

Principal Component Analysis (PCA) was applied to reduce the large number of variables to significantly important factors in order to provide a summary of the original data. After preliminary results of PCA in nonrotational and rotational modes (Varimax method) had similar answers, the varimax option was selected as a suitable method for selecting axes. In addition, Agglomerative Hierarchical Clustering (AHC) was applied for an easier identification of clusters. The biplot and dendrogram generated by the PCA and AHC, respectively, including the significant physical parameters of kernels are presented in Figure 6. The dendrogram showed the presence of three clusters as follows: (i) 'Belona', 'Masbovera', 'Ferragnès' and 'Soleta'; (ii) 'Jordi', 'Desmeus', and 'Penta'; (iii) 'Vivot', 'Marta', 'Vairo', Constantí', 'Feliu', 'Duareta', and 'Marinada'. These three groups were marked in the PCA biplot by colors, thus 1st group with green, 2nd group with purple, and 3rd group with an orange circle. The first two principal components (PC-1 and PC-2) presented in the biplot explained 55% of the total variability. All those green variables on the left side were negatively correlated with the green variables on the right side and were explained by the PC-1, while those red variables from the top side were negatively correlated with the red variables on the bottom and were explained by the PC-2. These chemometrics helped to extract useful information from the large morphological and physical data to group and characterize the samples. Based on the PCA results, the almonds from the first group were higher in size and weight and with a harder texture, while the contrary was observed for the second group with small, soft kernels with a red-yellowish skin. Finally, cultivars of the third group (manly the native cultivars) presented a higher thickness and a darker color, join with higher elasticity (extension before breakage). If this biplot is compared with the pedigree map of the modern cultivars (Figure 1) it can be highlighted that the cultivars originated from similar families inherited the parental genes responsible for the morphological and physical parameters of the kernels, because they are similarly clustered in Figure 6.

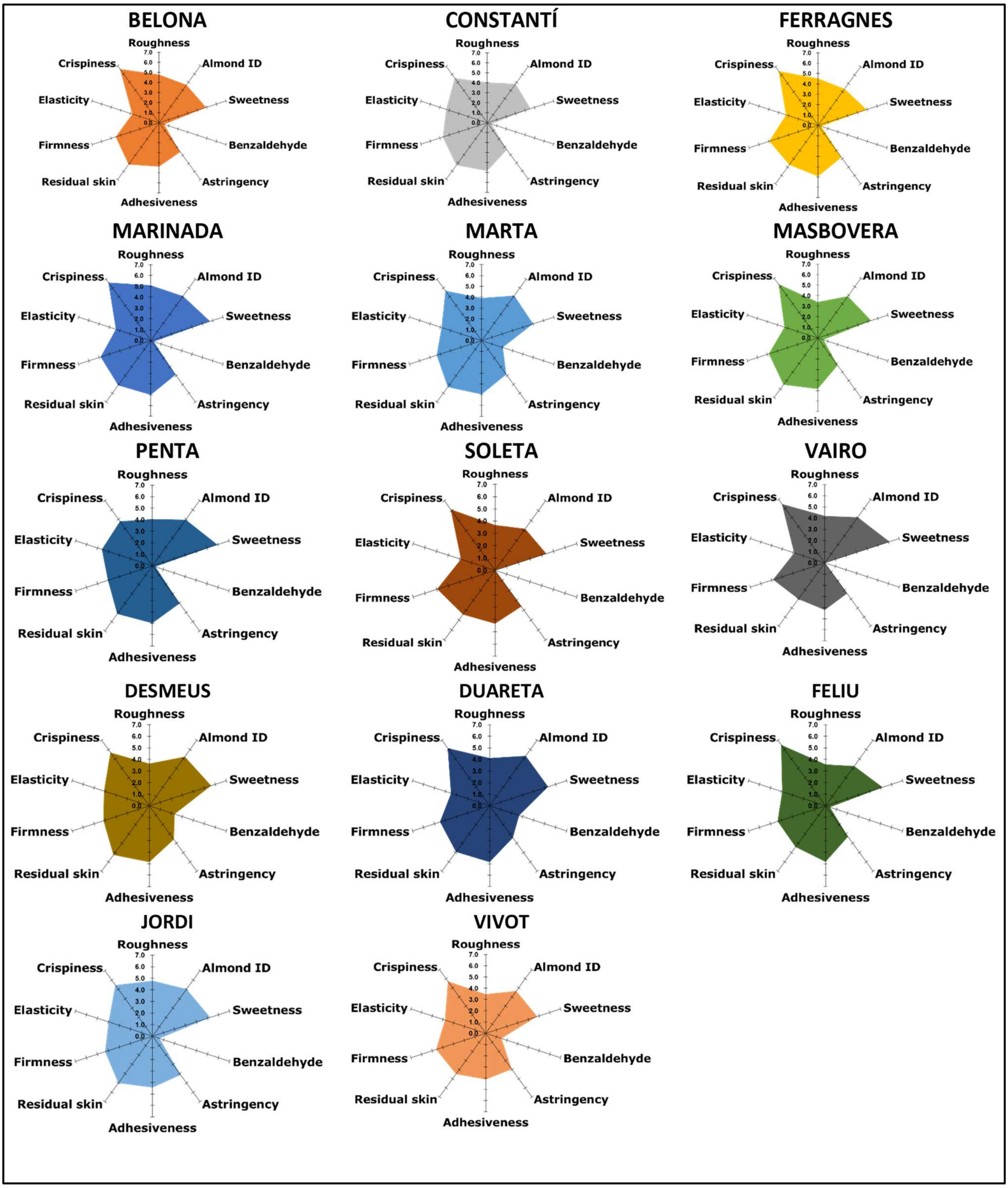

Figure 4. Sensory profile of each almond cultivar.

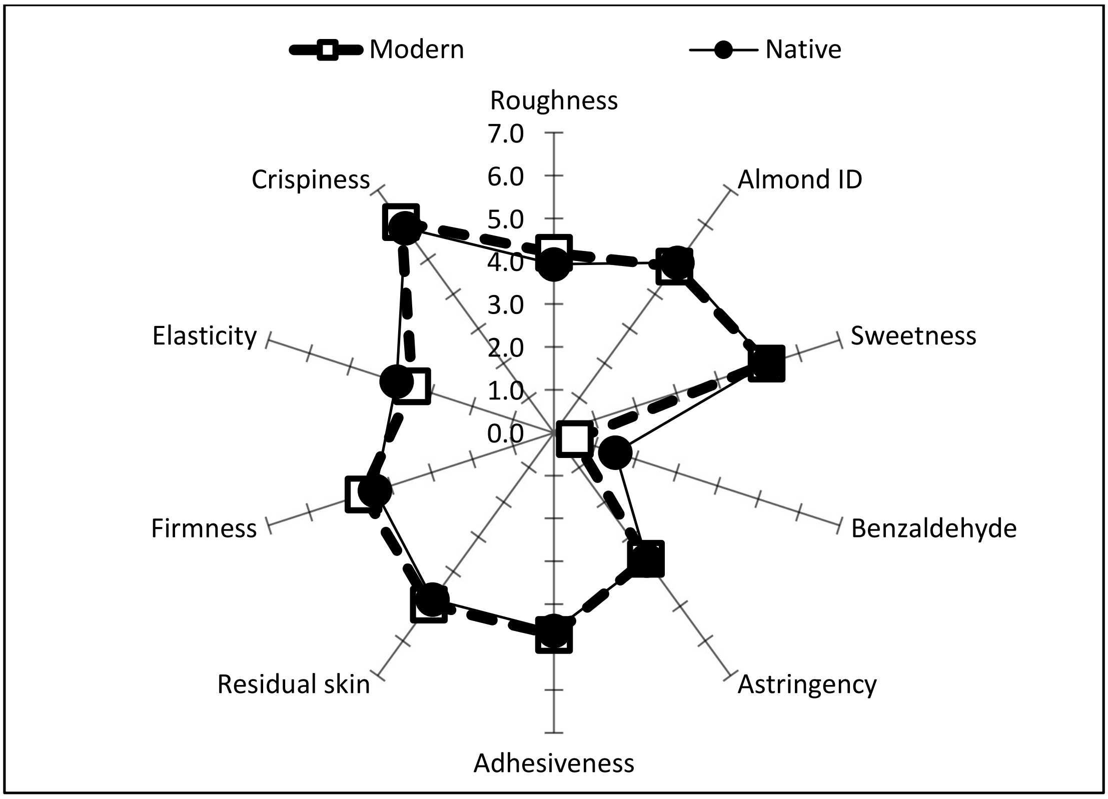

Figure 5. Sensory profile of the modern versus native almond cultivars.

For a better characterization of the samples, physical and nutritional parameters were decided to be divided, and the latter are plotted in Figure 7. The dendrogram helped to explore the organization of samples in also 3 groups depicting the complete hierarchy as follows: (i) 'Marta', 'Masbovera', 'Marinada', 'Penta', 'Desmeus', 'Constantí' and 'Feliu' was colored with a green circle; (ii) 'Ferragnès' and 'Vairo' with purple circle; and (iii) 'Duareta', 'Jordi', 'Soleta', 'Belona', 'Vivot' with an orange circle. Beside the proximate parameters, the fatty acids were also included in the chemometrics. In this sense, it can be observed that 3 of the native cultivars ('Jordi', 'Duareta', and 'Vivot') were mainly characterized by a high amount of fiber, fat, saturated (SFA) and polyunsaturated (PUFAs) fatty acids, while 'Feliu' and 'Desmeus' were higher in protein and monounsaturated (MUFAs) fatty acids which offer greater stability to the samples. As was expected, linoleic and so PUFAs were plotted on the opposite side of oleic acid, MUFAs and stability due to their strong negative correlations. The multiple double bonds of the PUFAs are more susceptible to degradation offering a low oxidative stability which may cause the formation of compounds with negative impact on health [67]. Thus, the presented results, might help to decide the processing option depending on the destination. About the genetical heritability regarding the chemical composition (Figure 7 compared to Figure 1), here the transfer is not as visible as in the morphological and physical traits, which explain that the breeders were mainly focused on satisfying the industry expectations which were mainly related to size, shape, and weight.

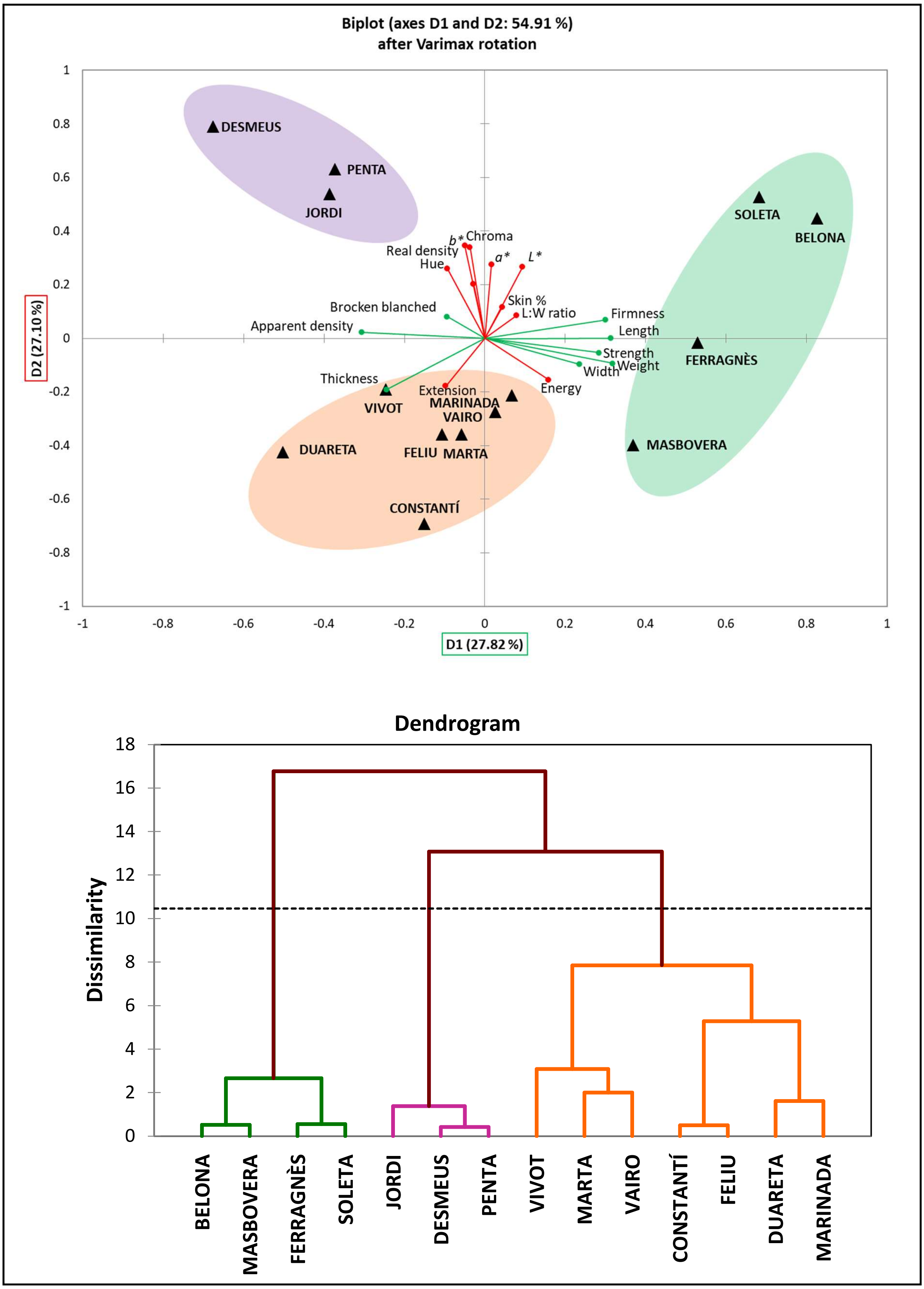

Figure 6. Principal Component Analysis (PCA) after Varimax rotation and Agglomerative Hierarchical Clustering (AHC) on physical parameters of kernel.

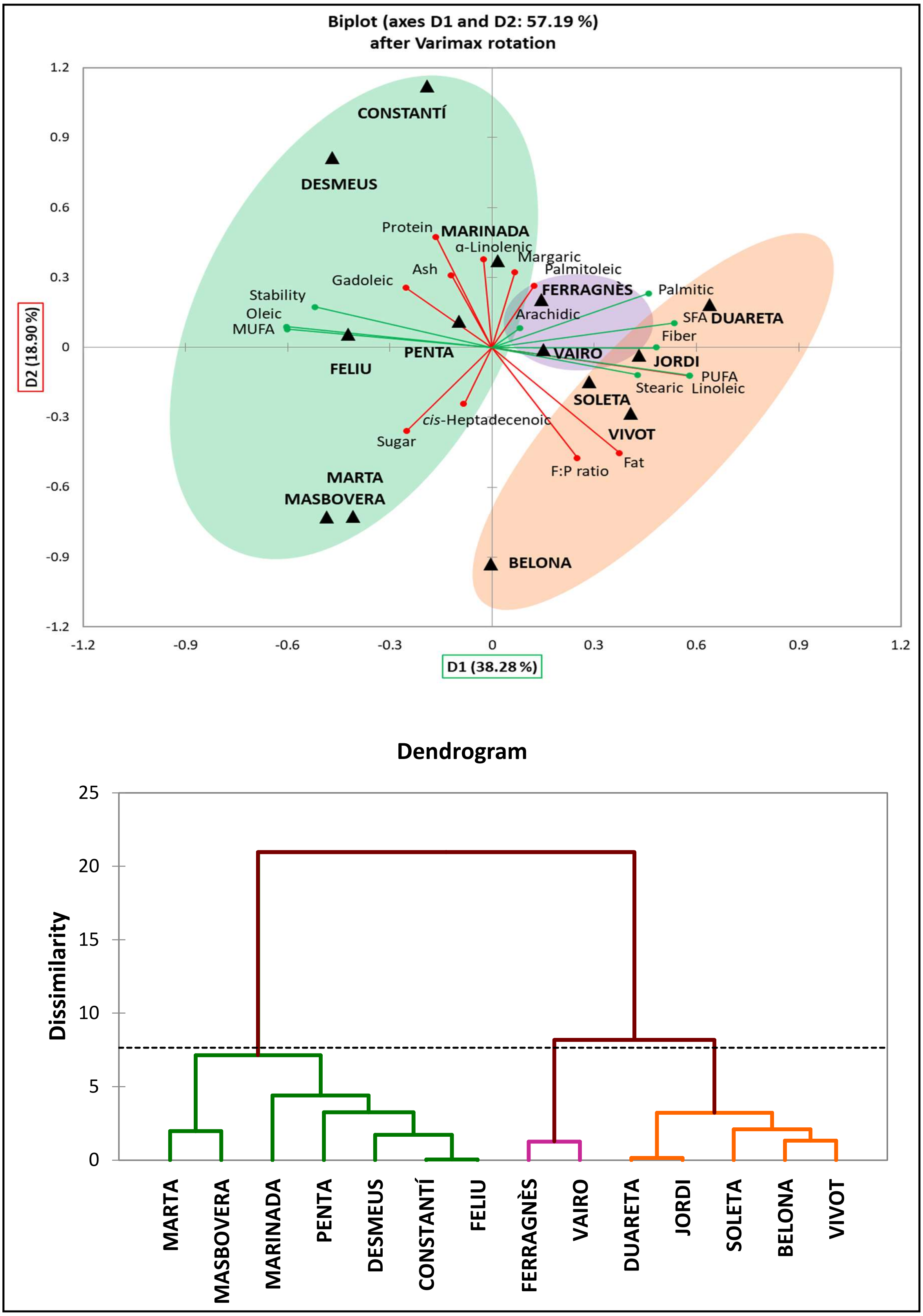

Figure 7. Principal Component Analysis (PCA) after Varimax rotation and Agglomerative Hierarchical Clustering (AHC) on chemical parameters of kernel.

4. Conclusions

Fourteen almond cultivars (nine were modern and five natives), growth in Mallorca Island were physically, chemically, and sensory characterized. The present results showed the uniqueness of each cultivar and the possibility to use them for different industrial purposes. Considering all the obtained results, general uses and recommendations attributed to each cultivar might be as following: (i) **'Belona'** could be used both for natural consumption (due to its weight, size, shape, light color, and hard texture), and for "*Turrón de Alicante*" or chocolate bar processing where perfect sectioned bars with whole almonds are needed. The high fat:protein ratio, is another important characteristic of this cultivarthat makes it suitable for "*Turrón de Jijona*" because the absorption of water by almond paste depends on the balance between these two parameters); (ii) **'Constantí'** is characterized by darker skin, high oil stability, and low fat content, which makes it appropriate for processed products such as low-calorie chocolate bars (where a lower amount of fat is needed to obtain a lower total caloric product), protein bars (due to their correlated high protein content), almond milk (to reach the caloric level of cow's milk) and flour (iii) **'Ferragnès'** cultivar could mainly work for consumption as raw or natural snack due to its light color, low benzaldehyde flavor and "crease" defect which is an inconvenient in processing operations (blanching or slicing); (iv) **'Marinada'** characterized by high weight kernels with low benzaldehyde flavor could be recommended for the same purposes as 'Belona' except for soft turrón; (v) **'Marta'** is highly recommended in processing products with high shelf life such as marzipan or others, due to its dark color skin, high oil stability and benzaldehyde flavor; (vi) **'Masbovera'** meet all the aspects mentioned for 'Belona' with the advantage that has a higher oil stability that can extend the product shelf life; (vii) **'Penta'** with the properties of low weight kernel, light color, high fat:protein ratio, high oil stability and low benzaldehyde flavor can be used in low-calorie chocolate bars, natural consumption, "*Turron*" industry with long shelf life storage; (viii) **'Soleta'** with a high length, light skin color, hard texture and low benzaldehyde flavor is highly recommended for natural snacks, chocolate bars and slices; (ix) **'Vairo'** cultivar is also a good candidate for natural consumption due to its low benzaldehyde flavor, but not for soft texture confectionery because of its high fiber content which is negatively correlated with soft texture products; (x) **'Desmeus'** has light skin color, low weight, fat content, fat:protein index and high benzaldehyde flavor which makes it adequate for low-calorie products, protein bars, almond flour, almond milk and mainly for marzipan; (xi) **'Duareta'** is characterized by dark skin color, low weight, high thickness, fiber, linoleic acid, benzaldehyde flavor and "twins". Thus, is highly recommended for low-calorie products, chocolate coated almonds, consumed as a snack for health purposes but not for long shelf-life products, high-quality slices or blanching operation; (xii) **'Feliu'** can be used for the same purposes as 'Duareta', due to its high thickness, dark skin color, and "crease" defect; (xiii) **'Jordi'** is characterized by high fat:protein index, fiber content, linoleic acid, broken pieces after blanching operation, "twins" and soft texture. Thus, blanching and slicing must be avoided; and (xiv) **'Vivot'** has also low weight which is ideal for chocolate industry, high fat:protein ratio for "Turrón" industry, high linoleic acid for health purposes and short shelf-life products. Finally, it can be said that most of the cultivars can be commercialized under the quality seal of PGI "*Almendra/Ametlla de Mallorca*", unless 'Constanti', 'Marinada', 'Desmeus', and 'Feliu' with a fat content below the required specifications. However, all cultivars meet the PGI "*Almendra de Mallorca*" criteria in terms of fatty acids ($\geq$ 88% of total lipids). Overall, the results provide useful information regarding modern cultivars in Mallorca terroir while characterization of the native almonds is of great importance due to its already adaptation to local environmental conditions. The study includes a comprehensive assessment from crop biodiversity to industrial aptitude of almonds and provide valuable information that may support producer decisions and predict the future industrial purpose of each cultivar. Further research during several growing cycles is needed to confirm these findings.

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