



Contents lists available at ScienceDirect

Food Science and Human Wellness

journal homepage: www.elsevier.com/locate/fshw

Almond cold-pressed oil by-product as ingredient for cookies with potential health benefits: Chemical and sensory evaluation

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ARTICLE INFO

Article history:

Received 17 May 2019

Received in revised form 21 July 2019

Accepted 24 July 2019

Available online 29 July 2019

Keywords:

By-products

Almond

Food security

Cookie formulation

Principal component analysis

ABSTRACT

Nowadays, food security is a global concern and a great scientific challenge. Agro-industrial by-products can be used as potential ingredients of innovative food products, contributing to solve this societal demand. By-products of high specialty oils processing, for instance, have remarkable nutritional and organoleptic properties. Accordingly, the partially delipidified almond flour (PDAF) remaining from almond oil extraction, was used as an alternative ingredient in a highly appreciated almond-based cookie (“almendrados”). For comparison purposes, four different “almendrados” formulations (one industrial, two with PDAF, and one with whole almond flour), were compared regarding nutritional composition, vitamin E and fatty acids profiles. To assess the cookie sensory properties, seventy-four consumers evaluated “appearance”, “taste”, “sweetness”, “crunchiness”, “hardness”, “overall quality” using adequate hedonic scales. Fat and protein levels showed significant differences among industrial and the other three samples. Cookies with PDAF presented similar tocopherols and fatty acids to the traditional (more expensive) formulation, besides reaching the highest scores on “appearance”, “sweetness”, “hardness”, “overall quality” and “buying predisposition” parameters. Accordingly, the incorporation of PDAF might represent an effective way of adding value to an industrial by-product, while providing a pleasant novel cookie formulation.

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1. Introduction

The current food security levels seem to be severely threatened by the exponential population growth, demanding finding alternative food sources without exhausting the agricultural sector [1]. One possible strategy regards the employment of industrial by-product as sources of ingredients with useful food applications, such as exemplified by the material remaining from cold-pressing extraction (CPE) of vegetable oils.

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Peer review under responsibility of KeAi Communications Co., Ltd.



<https://doi.org/10.1016/j.fshw.2019.07.002>

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Almond [*Prunus dulcis* (Mill.) D.A. Webb], a good example of a oleaginous seed, is produced mainly in the Mediterranean region and United States [2], which are the major producer and exporter of almond (37.2% of worldwide production), followed by Spain (12.1%), Australia (7.4%), Iran (5.2%), Morocco (5.1%), Italy (4.6%), and the Syrian Arab Republic (4.5%) [3]. Nowadays, there is an emerging trend to obtain almond oil by CPE, producing a high-value product with application in personal care products and high-specialty culinary purposes [2,4]. Contrarily to common practice, in which almond oil is extracted using solvents, CPE does not require a refining process to eliminate potential unpleasant flavours, representing also a sustainable methodology with reduced environmental impact quality [2].

Interestingly, the extraction of specialty oils is generating increasing amounts of high-potential by-products as exemplified by partially delipidified flours (PDF). Considering the current European sustainable development strategy, which preconizes the valorisation of what once was considered a “waste” to become a “valuable resource” (applying the concepts of circular economy),

finding new applications for PDF is a valuable way of “closing the loop” of product processing, which might convey important advantages for food security purposes [5]. From a nutritional point of view, the partially delipidified almond flour (PDAF), generated after oil extraction, contains all the bioactive constituents of almond tissues in addition to the high-interest lipophilic compounds present in its remaining oil fraction, constituting a by-product with high potentialities. In addition, the beneficial properties of almonds are well known, being acknowledged as important sources of healthy lipids, dietary fibre, protein, vitamin E, phytosterols and mineral elements. In fact, numerous studies correlated the daily consumption of almonds with health status improvement [3,6,7]. Accordingly, PDAF can be included in products designed to provide nutrients, but also prevent diet-related diseases and improve physical and mental well-being of consumers [8].

Furthermore, almonds are among the most versatile nuts in food industry, being commonly used as snacks (natural or roasted), pastries, almond syrup, nougat, marzipan, among others [2,7].

In this work, PDAF was used as substitute of whole almond flour in a traditional almond-based cookie, commonly known as “almendrado”. The nutritional composition, vitamin E and fatty acids profiles were compared among one industrial “almendrado”, two “almendrados” formulations using PDAF (with different sugar percentages) and one formulated with whole almond flour.

In order to evaluate if the replacement of whole almond flour by PDAF had influence on the cookies texture, mouthfeel and flavour, the consumer’s acceptance using sensory analysis was also assessed.

2. Materials and methods

2.1. Standards and reagents

Kjeldahl tablets catalyst ($\text{Na}_2\text{S}_2\text{O}_8/\text{CuSO}_4$), sulfuric acid (H_2SO_4) concentrated 96%, *n*-hexane HPLC and anhydrous sodium sulphate (Na_2SO_4) were obtained from Merck (Darmstadt, Germany). Sodium hydroxide (NaOH) and methanol were from VWR International (Leveun, Belgium). Boric acid (H_3BO_3) 4% and potassium hydroxide (KOH) were acquired from Panreac (Barcelona, Spain). Absolute ethanol was obtained from Fisher Chemical (Loughborough, England).

Tocol (2-methyl-2-(4,8,12-trimethyl-tridecyl) chroman-6-ol) was purchased from Matreya Inc. (Pennsylvania, USA). Tocopherols and tocotrienols standards: α -, β -, γ -, δ -tocopherol and α -, β -, γ - and δ -tocotrienol were acquired from Calbiochem (La Jolla, CA, USA). The mixture of fatty acid methyl esters standards (FAME) Supelco37 was obtained from Supelco (Bellefonte, PA, USA), 1,4-dioxane and petroleum ether were acquired from Sigma (St. Louis, MO, USA).

All chemicals and solvents were of analytical grade.

2.2. Sampling

The samples used in this study were 1) Industrial “almendrados” bought at a local grocery: AI; 2) “almendrados” produced in a local bakery “Confeitaria Luso”: AT; 3) “almendrados” produced at “Confeitaria Luso” with PDAF: AF; “almendrados” produced at “Confeitaria Luso” with PDAF and 30% sugar reduction: AFSR. All the “almendrados” manufactured in “Confeitaria Luso” were collected on the day of production and stored in cardboard boxes that allowed them to be kept fresh for the maximum possible time. The ingredient in evaluation (PDAF) was also assessed in what concerns nutritional composition.

Before analysis, the different samples were ground in a mill (GM Grindomix 200, Retsh, Germany) for 20 s at 1400 g to obtain a fine

powder. Then, samples were homogenized and properly stored at -20°C protected from light.

2.3. Nutritional analysis

Macronutrients were determined following the Association of Analytical Communities (AOAC) methods [9]. Moisture content was instrumentally determined using an infrared moisture analyser (SMO 01, Scaltec Instruments, Heiligenstadt, Germany). Ash content was determined by incinerating the sample in a muffle furnace at 550°C . Protein content ($N \times 6.25$) was determined using the Kjeldahl procedure. Total fat was determined by Soxhlet extraction with petroleum ether. Total carbohydrate content was determined by difference. Energy was calculated as: Energy (kcal) = $4 \times (\text{g protein} + \text{g carbohydrate}) + 9 \times (\text{g fat})$. The results were expressed as g per 100 g of fresh weight.

2.4. Vitamin E composition

For identification and quantification of vitamin E isoforms, standard solutions of α -, β -, γ - and δ -tocopherol and α -, β -, γ - and δ -tocotrienol were used (25, 18.75, 12.5, 6.25, 2.5 and 1.25 mg/ μL). Each of these solutions contained 20 μL of tocol (internal standard, 1 mg/mL).

In a centrifuge tube, ≈ 0.5 g of sample was weighed and mixed with 10 mL of *n*-hexane, 20 μL of internal standard (1 mg/mL) and 5 mL of absolute ethanol. Samples were vortexed (VWR International) and left under constant agitation for 30 min on a stir plate (MS-H-S10, DragonLab). Thereafter, 5 mL of 1% NaCl solution were added and the mixture was vortexed and centrifuged (Thermo Scientific, Heraeus Megafuge 16, USA) at 2800 g for 2 min. The organic phase was separated and the supernatant was transferred to a falcon tube. The residue was re-extracted three times with 10 mL of *n*-hexane. After each centrifugation, the supernatant was collected. The organic phases were combined and a sufficient amount of anhydrous sodium sulphate (Na_2SO_4) was added. The mixture was vortexed and centrifuged in order to collect the *n*-hexane layer and the extract was taken to dryness under a nitrogen stream (Sample Concentrator block heater BH200D/3), at room temperature. The residue obtained was reconstituted with 1 mL of *n*-hexane and stored (-20°C) till further analysis. All extractions were performed in amber glassware in order to be protected from light.

The chromatographic analysis was carried out in an HPLC integrated system equipped with an AS-2057 Plus automated injector, a PU-980 pump, a MD-2015 Plus multiwavelength diode array detector (DAD) and a FP-2020 Plus fluorescence detector (Jasco, Tokyo, Japan), programmed for excitation at 290 nm and emission at 330 nm [10]. The chromatographic separation of compounds was achieved on a normal phase Supelcosil™ LC-SI (3 μm ; 75 mm \times 3.0 mm; Supelco, Bellefonte, PA, USA). The injection volume was 20 μL , eluted with 1.8% dioxane in (V/V) at a flow rate of 0.8 mL/min. Chromatographic data were analysed using JASCO-Chrom NAV Software (version 1.18.03; Jasco, Tokyo, Japan). The compounds were identified based on their UV/vis spectra and the respective standards retention time. Quantification was based on the fluorescence signal response of each standard, converted to concentration units through calibration curves obtained from commercial standards of each compound, using the internal standard method. The results were expressed as mg/100 g of sample (fresh weight).

2.5. Fatty acids profile

For the extraction of the lipidic fraction, the methodology described in the previous section was used. The fatty acid methyl esters (FAME) were then obtained by cold transmethylation with

methanolic potassium hydroxide following ISO 12966-2 [11]. The derivatization process was initiated by mixing 40 mg of the extracted oil, 3 mL of *n*-hexane and 200 μ L of methanolic potassium hydroxide (2 mol/L).

After vortexing (1 min), Na_2SO_4 was added. This mixture was further vortexed and centrifuged (1000g, 5 min, Heraeus Sepatech Labofugue Ae, Heraeus Instruments, Hanau, Germany).

The supernatant was then transferred to a glass vial and analysed by gas chromatography in a Shimadzu GC-2010 Plus gas chromatograph equipped with a split-splitless injector, a flame ionization detector (FID) and an auto-injector Shimadzu AOC-20i (Shimadzu, Tokyo, Japan). A CPSil 88 fused silica capillary column (Varian, Middelburg, Netherlands; 50 m \times 0.25 mm i.d., 0.20 μ m film thickness) was used. Helium was the carrier gas (120 kPa) at a flow rate of 40 mL/min and separation was achieved with the following temperature program: 5 min at 140 °C, followed by an increase of 3 °C/min until 220 °C and maintained at 220 °C for 10 min. The temperatures of the injector and detector were 250 °C and 270 °C, respectively; a split ratio of 1:25 and an injection volume of 1 μ L were used. Each FAME was identified by direct comparison with a standard mixture (FAME 37, Supelco, Bellefonte, PA, USA) and analysed using the Shimadzu software GC Solution (v. 2.30, Shimadzu GC Solution, Shimadzu, Tokyo, Japan). The results were expressed in relative percentage of each FA, based on the relative peak areas.

2.6. Sensory analysis

Seventy-four consumers (57 women and 17 men) from 13 to 75 years old participated in the study. All the participants accepted voluntarily to do the evaluation and to be involved in the study. The samples presentation was the appropriate for the product, as well as the proposed questionnaire, according to ISO 16820:2004 and ISO 6658:2005. Each cookie was identified with a three-digit number randomly generated by a computer program. Consumers had to score the acceptability using a seven-point hedonic scale ranging from 1 (“dislike very much”) to 7 (“like very much”). For the buying predisposition, the scale ranged from 1 (“certainly not buy”) to 5 (“certainly buy”). The values were recorded on the card given to them for further evaluation. Participants were asked to evaluate “appearance” (uniformity of the external colour of cookie), “taste” (total intensity of taste that persists in the mouth after swallowing the sample), “sweetness” (sweet flavour intensity), “crunchiness” (energy with which the cookie makes crack-crunch-bang during the first two or three bites), hardness (force applied by the molar teeth to compress the food), “overall quality” (assessment taking into account all the characteristics analysed) and “buying predisposition” (intention to buy the product if commercially available).

2.7. Statistical analysis

For each formulation, three independent samples were analysed and each sample was analysed in triplicate. Data were expressed as mean \pm standard deviation. All statistical tests were performed at a 5% significance level using IBM SPSS Statistics for Windows, version 22.0. (IBM Corp., USA).

An analysis of variance (ANOVA), followed by Tukey’s test (homoscedastic distributions) or Tamhane’s T2 test (heteroscedastic distributions) was used to classify the statistical differences among “almendrados” formulations, in each of the assayed parameters. The fulfilment of the one-way ANOVA requirements, specifically the normal distribution of the residuals and the homogeneity of variance, was tested by means of the Shapiro Wilk’s and the Levene’s tests, respectively.

Aiming to identify which chemical and sensory characteristics were mostly related to consumers’ acceptability, the obtained

results were simultaneously studied by applying a principal components analysis (PCA), which allows categorizing the different correlations among studied variables and principal components. The number of dimensions kept for data analysis was assessed by the respective eigenvalues (which should be greater than one), by the Cronbach’s alpha value (that must be positive) and also by the total percentage of variance (that should be as high as possible) explained by the number of selected components. The number of plotted dimensions (two) was chosen in order to allow easier interpretations.

3. Results

3.1. Nutritional composition

Table 1 shows the mean values, in g/100 g of fresh weight (fw), of proximate composition of PDAF and also the four analysed formulations of “almendrados”. The most obvious differences were observed among industrial “almendrados” (AI), which showed the highest fat content (30 g), most likely due to the incorporation of lard (Supplementary material). In turn, this formulation presented the lowest levels of protein (3.7 g), carbohydrates (64 g) and moisture (1.6 g). Despite these differences, carbohydrates were the major component in all formulations, followed by fat or protein (depending on the formulation), water and ash. In cookies prepared with sugar reduction (AFSR), a higher decrease in carbohydrates content could be expected; however, considering the obtained results, it can only be concluded that a significant part of the carbohydrates were present as fibres, which is, in fact, in agreement with previous reports [12]. There was a significantly higher content in total mineral elements for AF and AFSR (1.4 and 1.7 g, respectively) when compared to the traditional formulation (0.82 g). Considering only cookies produced in the local bakery (AT, AF, and AFSR), the levels of fat and protein also showed statistically significant differences, with AT presenting the highest fat content (12 g), which might be explained by the fact of using whole almond flour; AFSR gave the highest protein content (13.9 g), most likely representing a proportional increase due to the lower carbohydrates content. Nevertheless, the increase in protein contents observed in comparison to AT, might also be explained by the incorporation of PDAF in AF and AFSR, since this product has a high protein content (43 g). The fat content of this by-product should also be highlighted, since nearly 50% of fat present in almonds [12] was maintained in PDAF after extraction. With the exception of this fat, the nutritional profile of PDAF is in agreement with the reported for whole almonds [13,14].

Besides the described improvements, the energy value of the new formulations represents an additional positive point, since AF and AFSR showed lower energy values (426 and 421 kcal, respectively); in either case, the energy values might be overestimated due to the presence of non-digestible fibres among the quantified carbohydrates).

3.2. Vitamin E composition

Table 2 shows the mean values obtained for tocopherols and tocotrienols profiles of each “almendrado” formulation. Considering the ingredients used, the main source of vitamin E is almond (or almond flour). Therefore, it was expectable to have α -tocopherol as the main vitamer, since it represents more than 90% of all vitamin E isoforms present in almond [12,15,16].

The profiles obtained for AT, AF and AFSR are, in general, in agreement with the previous considerations, but the vitamin E profile of AI clearly indicates the incorporation of other ingredients than those defined in the traditional recipe validated by the labelled

Table 1

Nutritional composition (g/100 g fresh weight) and corresponding energy for the studied “almendrados” formulations. PDAF values are also presented and used as reference. The results are presented as mean \pm SD.¹

	Moisture kcal	Fat kJ	Protein	Carbohydrates	Ash	Energy/100 g fresh weight		
Formulation	AI	1.6 \pm 0.1 ^d	30 \pm 1 ^a	3.7 \pm 0.2 ^d	64 \pm 1 ^c	0.81 \pm 0.03 ^c	539 \pm 3 ^a	2253 \pm 14 ^a
	AT	3.3 \pm 0.2 ^c	12 \pm 1 ^b	9.1 \pm 0.3 ^c	74 \pm 1 ^a	0.82 \pm 0.05 ^c	446 \pm 3 ^b	1865 \pm 14 ^b
	AF	4.2 \pm 0.1 ^b	10 \pm 1 ^c	10.4 \pm 0.5 ^b	75 \pm 1 ^a	1.4 \pm 0.1 ^b	426 \pm 2 ^c	1782 \pm 9 ^c
	AFSR	5.4 \pm 0.3 ^a	10 \pm 1 ^c	13.9 \pm 0.5 ^a	69 \pm 1 ^b	1.7 \pm 0.2 ^a	421 \pm 3 ^d	1761 \pm 13 ^d
Homoscedasticity ²	<i>p</i> -value (<i>n</i> = 36)	<0.001	0.452	0.007	0.360	<0.001	0.446	0.446
One-way ANOVA ³	<i>p</i> -value (<i>n</i> = 36)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
PDAF		7.1 \pm 0.2	27 \pm 1	43 \pm 1	18 \pm 1	5.5 \pm 0.3	483 \pm 3	2020 \pm 10

PDAF – partially delipidified flour; AI – industrial “almendrados”; AT – “almendrados” produced in a local bakery; AF – “almendrados” produced with PDAF; AFSR – “almendrados” produced with PDAF and 30% sugar reduction.

¹ Differences among means were evaluated using the Tukey’s HSD (homoscedastic distribution) or the Tamhane’s T2 (heteroscedastic distribution) multiple comparison tests.

² Homoscedasticity among formulations was tested by means of the Levene test: homoscedasticity, *p*-value > 0.05; heteroscedasticity, *p*-value < 0.05.

³ *p* < 0.05 meaning that the mean value of the evaluated parameter of at least one formulation differs from the others (in this case multiple comparison tests were performed).

Table 2

Vitamin E profile (mg/100 g fresh weight) for the prepared “almendrados” formulations. PDAF values are also presented and used as reference. The results are presented as mean \pm SD.¹

	α -Tocopherol	α -Tocotrienol	β -Tocopherol	γ -Tocopherol	β -Tocotrienol	δ -Tocopherol	Vitamin E	
Formulation	AI	1.9 \pm 0.2 ^d	0.85 \pm 0.04 ^a	0.70 \pm 0.02 ^a	1.8 \pm 0.2 ^a	0.82 \pm 0.04	1.0 \pm 0.1 ^a	7.2 \pm 0.3 ^a
	AT	4.9 \pm 0.2 ^a	0.19 \pm 0.02 ^b	0.06 \pm 0.01 ^c	0.13 \pm 0.01 ^b	nd	0.026 \pm 0.003 ^b	5.3 \pm 0.2 ^b
	AF	2.7 \pm 0.2 ^c	0.11 \pm 0.02 ^c	0.04 \pm 0.01 ^c	0.15 \pm 0.02 ^b	nd	0.028 \pm 0.002 ^b	3.1 \pm 0.2 ^c
	AFSR	4.1 \pm 0.3 ^b	0.22 \pm 0.03 ^b	0.41 \pm 0.05 ^b	0.12 \pm 0.02 ^b	nd	0.029 \pm 0.003 ^b	5.0 \pm 0.5 ^b
Homoscedasticity ²	<i>p</i> -value (<i>n</i> = 36)	0.387	0.057	0.004	<0.001	–	<0.001	0.034
One-way ANOVA ³	<i>p</i> -value (<i>n</i> = 36)	<0.001	<0.001	<0.001	<0.001	–	<0.001	<0.001
PDAF		11 \pm 1	0.40 \pm 0.03	0.13 \pm 0.02	0.32 \pm 0.03	nd	0.08 \pm 0.01	12 \pm 1

PDAF – partially delipidified flour; AI – industrial “almendrados”; AT – “almendrados” produced in a local bakery; AF – “almendrados” produced with PDAF; AFSR – “almendrados” produced with PDAF and 30% sugar reduction.

¹ Differences among means were evaluated using the Tukey’s HSD (homoscedastic distribution) or the Tamhane’s T2 (heteroscedastic distribution) multiple comparison tests.

² Homoscedasticity among formulations was tested by means of the Levene test: homoscedasticity, *p*-value > 0.05; heteroscedasticity, *p*-value < 0.05.

³ *p* < 0.05 meaning that the mean value of the evaluated parameter of at least one formulation differs from the others (in this case multiple comparison tests were performed).

information (Supplementary material). The fact that β -tocotrienol has been exclusively detected in AI could be indicative of using wheat flour [17] (which is not one of “almendrados” ingredients), but this kind of assumptions is merely speculative at this point. In addition, considering the used ingredients in AI formulation, eggs were expected to contribute with α - and γ -tocopherol [18]. The higher tocopherol values of AI are also the result of its higher fat percentage, since results are presented in fresh weight basis.

Among traditional recipe-base “almendrados”, AT gave the highest α -tocopherol content (4.9 mg), probably due to their high content in whole almond flour, which contains nearly 60% of fat [12], in comparison to the 27% presented by PDAF. The differences measured for the remaining vitamers were less pronounced, especially for γ - and δ -tocopherol, which did not show statistically significant differences.

Regarding total vitamin E contents, AI showed the highest values (7.2 mg) followed by AT (5.3 mg), AFSR (5.0 mg) and AF (3.1 mg). The lowest vitamin E content is probably justified by the lower overall proportion of fat in the formulation, either due to the addition of less sugar in AFSR, or the use of whole almond flour in AT, instead of PDAF in AF.

3.3. Fatty acids profile

The fatty acids (FA) profiles obtained for each formulation, as well as that corresponding to PDAF are presented in Table 3. AT, AF and AFSR showed very similar profiles, contrarily to the industrial formulation (AI), certainly due to the inclusion of lard in this recipe. For all “almendrados” prepared in the bakery store, the percentage of unsaturated fatty acids was above 90%, with \approx 70% of MUFA

and \approx 20% of PUFA. Oleic acid was clearly the most abundant FA (67%–69%), followed by linoleic acid (21%–23%) and palmitic acids (6.8%–7.1%).

In most cases, the FA of those three formulations did not present statistically significant differences. Their overall profiles were very similar to that of PDAF, which might be considered as an interesting nutritional feature. As it was expected, the FA profile of PDAF is nearly the same as that typically characterized in almond samples [12,16]. On the other hand, AI presented a high percentage of saturated fatty acids (41%), mostly due to the contribution of palmitic acid (C_{16:0}) and stearic acid (C_{18:0}), which are among the main FA in lard.

Overall, it should be highlighted that the beneficial FA profiles presented by AT were fully maintained in AF and AFSR.

3.4. Sensory analysis

During product development, food companies concern about how consumers will appreciate the sensory characteristics of the product and which sensory attributes will drive their acceptability, aiming designing food products that fully match consumers’ expectations, preferably if these contribute to their wellness [19,20]. Accordingly, the consumers’ acceptability of “almendrados” incorporating PDAF, together with “almendrados” obtained by three different recipes (including the traditional), were evaluated by a group of 74 tasters that filled up a 10 parameter questionnaire based in a 7-level hedonic scale for each question (except in the case of “buying predisposition”, where a 5-level scale was used). The sensory quality of “almendrados” was evaluated by rating their “appearance”, “taste”, “sweetness”, “crunchiness”, “hardness” and

Table 3
Fatty acids profile (relative percentage) for the prepared “almendrados” formulations. PDAF values are also presented and used as reference. The results are indicated as mean \pm SD.¹

		C14:0	C16:0	C16:1	C18:0	C18:1n9c	C18:2n6c	C18:3n3	SFA	MUFA	PUFA
Formulation	AI	1.0 \pm 0.1 ^d	24 \pm 1 ^a	1.4 \pm 0.1 ^a	16 \pm 1 ^a	42 \pm 2 ^c	14 \pm 1 ^c	0.57 \pm 0.05	41 \pm 1 ^a	44 \pm 2 ^c	15 \pm 1 ^c
	AT	nd	6.9 \pm 0.4 ^b	0.52 \pm 0.05 ^b	2.1 \pm 0.3 ^b	69 \pm 1 ^a	21 \pm 1 ^b	nd	9 \pm 1 ^b	70 \pm 1 ^a	21 \pm 1 ^b
	AF	nd	6.8 \pm 0.4 ^b	0.48 \pm 0.03 ^b	2.3 \pm 0.2 ^b	67 \pm 1 ^b	23 \pm 1 ^a	0.04 \pm 0.01	9 \pm 1 ^b	68 \pm 1 ^b	23 \pm 1 ^a
	AFSR	nd	7.1 \pm 0.4 ^b	0.50 \pm 0.05 ^b	2.3 \pm 0.2 ^b	67 \pm 1 ^b	23 \pm 1 ^a	nd	9 \pm 1 ^b	68 \pm 1 ^b	23 \pm 1 ^a
Homoscedasticity ² One-way ANOVA ³	p-value (n = 36)	–	0.385	0.433	0.006	0.112	0.811	<0.001	0.127	0.129	0.842
	p-value (n = 36)	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
PDAF		nd	7.0 \pm 0.4	0.54 \pm 0.05	2.6 \pm 0.3	68 \pm 1	21 \pm 1	0.24 \pm 0.05	10 \pm 1	69 \pm 1	21 \pm 1

PDAF – partially delipidified flour; AI – industrial “almendrados”; AT – “almendrados” produced in a local bakery; AF – “almendrados” produced with PDAF; AFSR – “almendrados” produced with PDAF and 30% sugar reduction.

¹ Differences among means were evaluated using the Tukey’s HSD (homoscedastic distribution) or the Tamhane’s T2 (heteroscedastic distribution) multiple comparison tests.

² Homoscedasticity among formulations was tested by means of the Levene test: homoscedasticity, p -value > 0.05; heteroscedasticity, p -value < 0.05.

³ p < 0.05 meaning that the mean value of the fatty acid percentage of at least one formulation differs from the others (in this case multiple comparison tests were performed).

“overall quality”. In addition, the “buying predisposition” was also evaluated. The 74 tasters had ages varying among 13 and 75 years old, with high predominance of individuals with ages between 21 and 50 years (52 individuals).

Independently of the formulation, the majority of tasters liked the appearance of “almendrados”, but traditional formulations were more highly appreciated (61 individuals liked the appearance of AFSR, 62 of AF, 63 of AT, but only 39 liked the appearance of AI). Interestingly, 29 tasters “liked very much” the formulation incorporating PDAF, which is a strong indicator of the potential acceptability of “almendrados” added with the by-product studied herein.

The results obtained for “overall taste” are very similar to those obtained for “appearance” criterion, with “almendrados” produced at the bakery store obtaining the highest scores. However, the number of individuals that “like very much” (AT: 12; AF: 10; AFSR: 4) was not as high as the one obtained for “appearance” criterion, which might indicate a certain need towards improving the corresponding formulations. Even so, there seems to be a strong correlation among “overall taste”, “sweetness” and “crunchiness”, since results obtained from the 74 tasters were nearly the same for the three criteria. Curiously, sugar reduction did not affect the “sweetness” sensation, which should be considered as an interesting result, since it indicates the possibility of reducing sugar content in 30% without affecting the pleasant sweet sensation, while achieving potential health benefits. In fact, 53 individuals liked the AFSR formulation, exactly the same number of those that liked the AF formulation; 55 liked the AT formulation and only 42 indicated to like AI. Among these individuals, the most frequent answer was “like moderately”, which indicates that sugar content could be optimized, especially taking into account the low number of individuals that answered “like very much” in this parameter. The same conclusion could be inferred from “crunchiness” results.

The results obtained for “hardness” were not as good as those acquired for the previous criteria. The majority answered to be satisfied with this parameter, but the number of “like slightly”, “like moderately” or “like very much” answers decreased. This might be related with the participation of older people, who are more prone to classify this type of food products as being hard or crusty.

Nevertheless, results obtained for “overall quality” criterion were highly satisfactory, especially for AT (17 “like slightly”, 18 “like moderately”, 16 “like very much”), AF (19 “like slightly”, 24 “like moderately”, 14 “like very much”) and AFSR (20 “like slightly”, 17 “like moderately”, 10 “like very much”). On the other hand, less than 50% of tasters declared to have liked of the “overall quality” of AI.

The results described hitherto are reflected in answers obtained in the question regarding the potential purchase of the tasted prod-

ucts. In this criterion, the best scores were registered for AF (24 “I’d probably buy” and 25 “I’d certainly buy” answers), with AT (16 “I’d probably buy” and 22 “I’d certainly buy” answers) and AFSR (26 “I’d probably buy” and 10 “I’d certainly buy” answers) showing very similar results.

In general, the sensory analysis highlighted AT, AF and AFSR as the best formulations. Despite the similarity in results obtained for these three formulations, AF seems to have gathered the overall preference of the 74 tasters, as it might be observed in Fig. 1.

3.5. Principal component analysis

To validate the previous assumption, as also to identify which chemical and sensory characteristics were mostly correlated to consumers’ acceptability, all results were studied simultaneously by applying a principal component analysis (PCA) to categorize the correlations among studied variables and principal components.

PCA was applied by considering average values obtained for all parameters, using “almendrados” formulation as labelling variable. In the performed analysis, three significant dimensions were obtained, from which the first two (1st: Cronbach’s α = 0.984; eigenvalue = 22.019; 2nd: Cronbach’s α = 0.865; eigenvalue = 6.218) were plotted (Fig. 2).

Groups corresponding to each “almendrados” formulation correlated differently with the defined principal components. The markers belonging to AT and AFSR were distributed in the top left quadrant, while those corresponding to AF were located in bottom left quadrant. AI formulation correlated only with the first dimension, since it is nearly superimposed to the origin axis of dimension 2.

Curiously, all markers linked to consumers’ acceptability (except for crunchiness) were located in bottom left quadrant, thereby irrefutably indicating that the AF formulation was the most appreciated. Following the same reasoning, AI (which is in opposite position to AF) was clearly the least appreciated formulation.

The reduction of fat content (up to 50% less fat) was previously reported as being well accepted by consumers [22], but the formulations prepared herein were classified as being even better than the traditional recipe. This is a very interesting result, since the most highly appreciated “almendrados” were prepared by replacing whole almond flour by PDAF, which allows a significant reduction in the production cost and a very useful way of using the by-product remaining from almond oil CPE.

Another interesting point was the close location of AT and AFSR, which shows that these two formulations scored very similarly in all chemical and sensory indicators. Usually, consumers are only slightly receptive to cookies prepared with sugar reduction [21], but in the case of “almendrados” this tendency was not noticeable,

might be limited to the studied population (sensory sensitiveness is known to be influenced by geographical origin), it was possible to innovate the recipe of a traditional product through the incorporation of an otherwise underutilized by-product, while fulfilling modern circular economy (zero waste) requirements and developing a product that fits the current food security challenges, besides presenting good sensory quality.

Declaration of Competing Interest

None.

Acknowledgments

The work was supported by UID/QUI/50006/2019 and UID/AGR/00690/2019 with funding from FCT/MCTES. J.C.M. Barreira is grateful for his CEEC contract. M. Antónia Nunes (SFRH/BD/130131/2017), and F.B. Pimentel (SFRH/BD/109042/2015) thank FCT and European Social Fund through Programa Operacional Capital Humano.

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