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ORIGINAL PAPER

Comparison of different drying methods on the chemical and sensory properties of chestnut (*Castanea sativa* M.) slices

Teresa Delgado[1,2] · José Alberto Pereira[1] · Elsa Ramalhosa[1] · Susana Casal[2]

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Abstract The aim of this work was to determine the effect of hot-air convective drying (D), osmotic dehydration (OD), osmotic dehydration + drying (OD + D) and freeze-drying (FD) on chemical and sensorial characteristics of chestnut slices. Proximate composition, sugars, organic acids and lipid profiles were determined along 60 days of storage. Immediately after production, D and FD samples had similar proximate compositions, both with higher fat and protein contents than the osmodehydrated ones, the latter with increased sucrose contents. FD was the method that better preserved starch, amylose, ascorbic and citric acid molecules at day 0, while D originated samples with higher glucose and fructose contents. Along storage, the major variations were observed on organic acids: ascorbic acid decreased on all methods, while fumaric acid increased. Only small variations were observed on the fatty acids and vitamin E profiles and amounts. All samples presented similar and good overall sensorial acceptance with the exception of D. FD was the method that better preserved the sensorial characteristics until 60 days of storage, while D only preserved freshness until 15 days and OD + D until 30 days. In general terms, the most adequate and accepted preservation methods to apply to chestnuts would be FD and OD + D.

✉ Elsa Ramalhosa
elsa@ipb.pt

[1] Centro de Investigação de Montanha (CIMO), ESA, Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal

[2] LAQV@REQUIMTE, Laboratório de Bromatologia e Hidrologia, Faculdade de Farmácia da Universidade do Porto, Rua de Jorge Viterbo Ferreira, no. 228, 4050-313 Porto, Portugal

Keywords *Castanea sativa* Mill · Dehydration methods · Chemical composition · Sensory analysis · Shelf-life

Introduction

Currently, there is growing interest in healthier snacks, as alternative to fried ones, by application of different preservation methods to improve shelf-life of several perishable products, particularly those with higher water content, such as fruits and vegetables.

There are several industrial dehydration methods, including hot-air convective drying, osmotic dehydration and freeze-drying, among others. These technologies can be a good alternative choice to produce healthy snacks. Hot-air convective drying (D) is the most common dehydration method and has an important role in the food processing industry. Other dehydration method with interesting results is osmotic dehydration (OD), a quite simple cost-effective technology, used since ancient times to preserve perishable items and make them available to distant regions and through the year [1, 2]. Even though freeze-drying (FD) has high productive costs, it works at low temperatures, enabling a more efficient preservation of natural constituents [3], being also an interesting method to produce natural snacks.

Some new snacks based on dehydrated fruits such as apple, pear, strawberry, peach and pineapple, are beginning to emerge on the market; however, none uses chestnuts. From the nutritional point of view, chestnut can be quite interesting. Besides being gluten-free [4], chestnut is a good source of fibre, starch, protein, amino acids, minerals, organic acids, and vitamins, among others. Even though some individual studies on hot-air convective drying and osmotic dehydration of chestnut have been performed

[5–15], none has compared the effects of these drying technologies to chestnut slices and, in addition, their sensory acceptance along storage time. So, the present work had two main objectives: (1) to evaluate the effect of applying four different dehydration methods to produce dehydrated chestnut slices to be consumed as an healthy snack: hot-air convective drying (D), osmotic dehydration (OD), osmotic dehydration followed by hot-air convective drying (OD + D) and freeze-drying (FD); and (2) to verify the acceptability and durability of the developed products by sensory analysis.

Materials and methods

Chemicals and standards

All standards for the lipid profile, sugars and organic acids were purchased from Sigma (St. Louis, MO, USA). All other chemicals were of analytical grade from diversified suppliers.

Dehydration procedures

The chestnut fruits (*Castanea sativa* M., Longal variety) used in this study were acquired in Bragança (Northeast Portugal) in November 2014 and stored in cold chambers (4 ± 1 °C) until the experimental procedure was carried out. Longal was the chestnut variety chosen because it is one of the most representative in Bragança region and it is easy to peel. Chestnuts were used after removing carefully the exterior shell with a knife and after being sliced with approximately 2–3 mm of thickness.

Four processes were applied for chestnut slices dehydration. In more detail, around 500 g of chestnut slices was dried in an oven with forced convection (Binder, FD 240, Tuttlingen, Germany) at 50 °C, during 3 h, to achieve the desired crispy texture [drying method (D)], with a final moisture content of 14.0%. The same amount of chestnuts was freeze-dried (ScanVac, CoolSafe, Lynge, Denmark) during 24 h (freeze-drying method (FD)), with a final moisture content of 13.1%. Simultaneously, around 600 g of chestnuts were osmotic dehydrated in a sucrose solution (83%, w/v) during 9.2 h at 20 °C (osmotic dehydration method (OD)), with a final moisture content of 22.9%. Afterwards, the dehydrated chestnut slices were removed from the solution, drained, and gently cleaned with absorbent paper to remove any sugar solution in excess. Furthermore, one portion of the osmotic dehydrated samples was further dried in a stove at 50 °C during 3 h (OD + D method) (moisture content equal to 7.1%). It must be referred that the OD conditions were optimised in a previous work performed by our research group, to obtain the highest water loss and the lowest solids gain and colour variation (data not shown) [16].

All samples were divided in sealed polyethylene bags, and stored during 7, 15, 30, 45 and 60 days at room temperature (approx. 20 °C) in the dark (protected with aluminium foil) to simulate usual storage conditions. After each predefined storage time, samples were tested by the sensory panel and a portion was immediately frozen, freeze-dried, ground (IKA-WERKE, M20, Staufen, Germany), and stored at −20 °C until all the following determinations were carried out. For the osmotic dehydration method, only the first sample was analysed (0 days of storage time) because the OD chestnut slices spoiled easily due to their high water activity (0.879), measured in a water activity meter of Novasina (Labswift-aw, Lachen, Switzerland). Indeed, after 7 days, the samples presented off-flavours and were unsuitable to eat, being discarded. Furthermore, after treatments and storage, the dry matter contents of all samples were determined.

Nutritional composition

All samples were analysed to determine their proximate composition, following AOAC procedures [17], at 0, 30 and 60 days of the storage time, with the aim to evaluate the occurrence of some modifications on the nutritional composition of the chestnut slices along storage. The crude protein content of the samples was estimated by the macroKjeldahl method, using a conversion factor of 5.3 [18]; crude fat was determined by extracting 5 g of sample with petroleum ether for 24 h, using a Soxhlet apparatus. The neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined by the method described by Goering and Van Soest [19]. All results were expressed on percentage (g/100 g dry matter).

Free sugar analysis

Dry samples (300 mg, in duplicate) were mixed with an internal standard (rhamnose; 50 mg/mL; 200 µl), and let to hydrate and swell with 5 mL of water:ethanol solution (20:80, v/v) for 30 min in a vortex. To increase cell disruption and extractability, the tubes were placed in an ultrasound bath for 5 min (Elmasonic S60h, Singen, Germany), followed by 30 min in a water bath at 60 °C. The solutions were centrifuged at 840*g* for 5 min at room temperature. The supernatants were transferred to a second vial and the residue was further extracted with 5 mL of the same solution. Both supernatants were mixed together. 2 mL of the supernatant were concentrated at 60 °C under nitrogen flushing for total ethanol removal. The solution was taken up to 1 mL with ultra-pure water, mixed in a vortex, transferred to an Eppendorf, centrifuged at 16060*g* for 15 min

at 0 °C, and filtered through 0.22 µm Nylon filters before injection.

The extracted free sugars were analysed in a Jasco integrated high performance liquid chromatographic system (Tokyo, Japan), equipped with an autosampler (AS-2057 Plus), a PU-980 intelligent pump, coupled to an evaporative light scattering detector (ELSD) (Sedere Model 75, Olivet, France). The HPLC system was equipped with a SUPELCOGEL Ca column (300 × 7.8 mm, Supelco, Bellefonte, PA, USA), operating at 80 °C. The mobile phase was ultra-pure water at a flow rate of 0.7 mL/min. The optimised detector temperature and gas pressure were 40 °C and 2.4 mbar, respectively. The results were expressed on g/100 g (dry weight), calculated by internal normalisation of the chromatographic peak area and application of individual calibration curves. Each sample extract was injected twice. Sugar identification was made by comparing the relative retention times of sample peaks with those of standards, standard addition, and literature data.

Starch and amylose contents

The starch and amylose contents were determined by application of the Megazyme kit (Megazyme procedure, K-AMYL 07/11, Wicklow, Ireland). The principle of this kit is that amylopectin complexes with lectin concanavalin (Con A), while the primarily linear amylose component is not able to complex with it. Moreover, total starch is hydrolysed to D-glucose and measured colourimetrically. Thus, in the present work, total starch was extracted and determined by the procedure described on the Megazyme kit, using the starch standard included in it. The results were expressed on starch percentage in the sample (by dry weight) and amylose percentage in the starch (g of amylose/100 g of starch).

Organic acids analysis

The organic acids extraction was performed according to the method described by Carocho et al. [20] with some modifications, namely the addition of internal standard and the application of a sequential extraction. In more detail, samples (500 mg, in duplicate) were mixed with 5 mL of meta-phosphoric acid (3%, w/v) and 150 µL of gallic acid, as internal standard (1 mg/mL), for 30 min in a vortex. Then, the solutions were centrifuged (Heraeus Sepatech, Am Kalkberg, Germany) at 840*g* for 5 min at 20 °C. The supernatants were removed and 5 mL of meta-phosphoric acid (3%, w/v) were added to the residue, being the extraction process repeated. The supernatants were combined and approximately 1 mL of the supernatant was filtered through 0.22 µm Nylon filters before high performance liquid chromatography—ultraviolet detection (HPLC–UV) analysis.

Organic acids were determined in a Jasco integrated system (Easton, USA) equipped with an autosampler (AS-2057 Plus), a PU-980 intelligent pump, coupled to an UV detector set at 215 nm (UV-975). The HPLC system was equipped with a C_{18} column (150 × 4.6 mm, 5 µm, Gemini NX, Phenomenex, Torrance, USA) operating at room temperature. The mobile phase was sulfuric acid (3.6 mM) at a flow rate of 0.7 mL/min. The results were expressed in mg/100 g of dry weight, calculated by internal normalisation of the chromatographic peak area and individual calibration curves. Organic acids identification was made by comparing the relative retention times of sample peaks with standards. In Fig. 1a, it is shown a typical chromatogram obtained for a chestnut sample.

Lipid analysis

Fatty acids and vitamin E extraction and quantification were performed according to the method described by Delgado et al. [21], based on cold lipid extraction, followed by direct analysis of vitamin E by normal-phase HPLC and conversion of all glycerides to fatty acid methyl esters and their analysis by gas chromatography. In Fig. 1b, it is shown a typical chromatogram obtained for vitamin E quantification in a chestnut sample.

Sensory analysis

The quality of the dried products was also evaluated by sensory analysis, at 0, 7, 15, 30, 45 and 60 days. The sensory analysis of these samples was carried out by a panel of 11 semi-trained judges, who took part in previous training sessions, where particular attribute definitions were discussed and clarified. The sensory descriptors used were sweetness, hardness, crunchiness, freshness, and overall acceptance. The results were transposed into a 1–10 point scale, where “1” denoted the absence of a given trait or an unacceptable level, while “10” indicated an intensive sensation or high quality.

Statistical methods

The statistical analysis was performed on SPSS software (Version No. 20.0). The effect of the four dehydration processes and storage time over chestnut slices chemical composition was evaluated by a two-way analysis of variance (ANOVA) ($p < 0.05$), followed by the Tukey HSD Post hoc test, since data normality was observed and the variances of the groups were identical. The normality and variance homogeneity were evaluated by the Kolmogorov–Smirnov and Levene’s tests, respectively. Comparisons were carried out at 95% confidence level. A Principal Component Analysis (PCA) was also performed to the results of the four dehydration processes. The PCA score plot was used

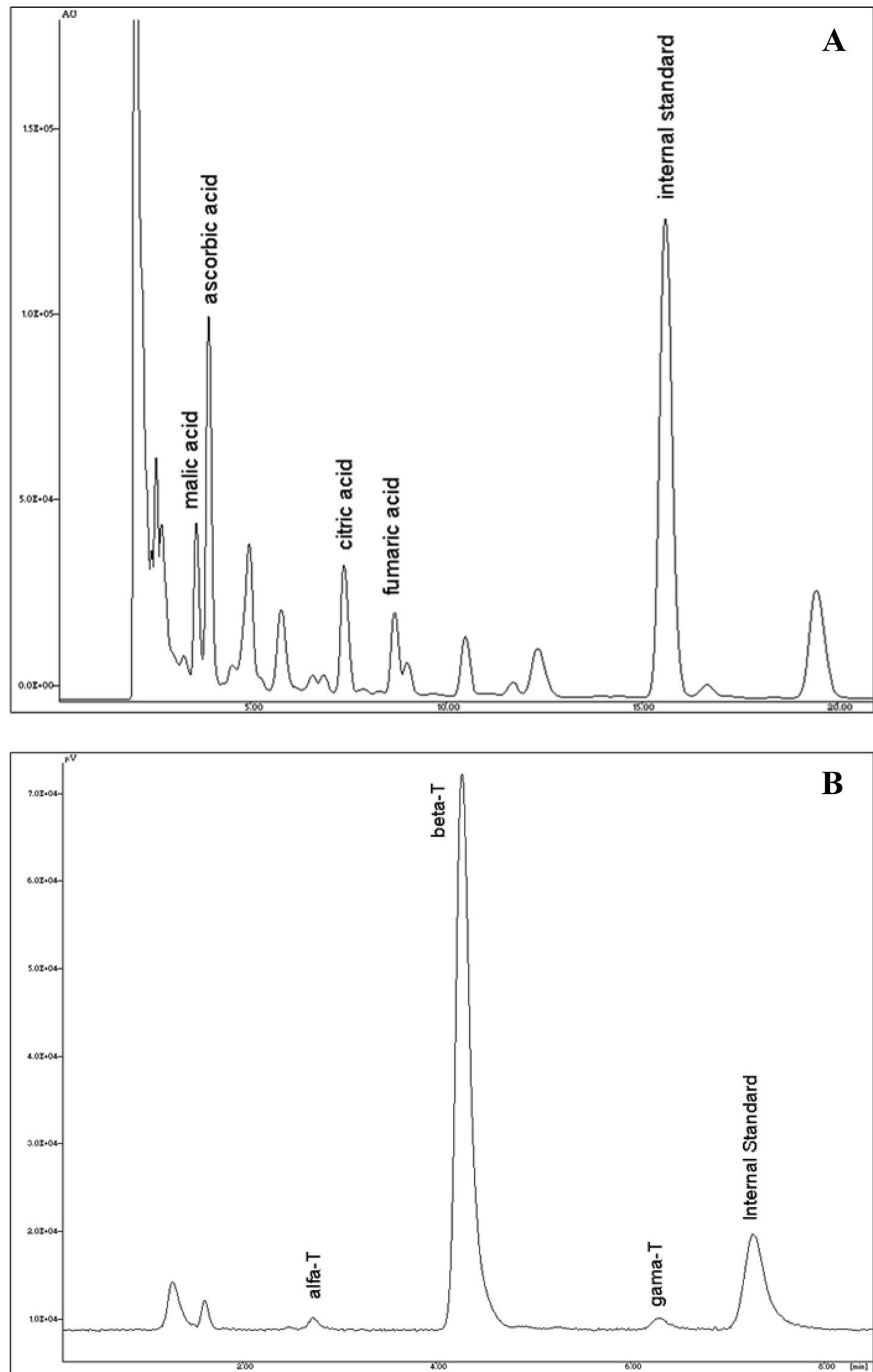

Fig. 1 Chromatograms of organic acids (**a**) and vitamin E (**b**) for a chestnut sample

to differentiate dehydration processes and verify their effect on the chemical composition of chestnut slices.

Results and discussion

The results obtained for the physicochemical composition and sensory analysis of the chestnut slices dried by the four dehydration methods, along the storage time, are shown in Tables 1, 2, 3 and 4. In almost all situations, significant interactions between treatment and storage time were observed ($p < 0.05$), except in γ-tocopherol, hardness and overall acceptance. However, for these properties the individual effects of dehydration method and/or storage time were significant.

Table 1 Proximate composition of chestnut slices dried by different methods along the storage time

Parameter	Storage time			p
	0 days	30 days	60 days	Treatment × time
Crude fat (g fat/100 g dry weight)				
OD	2.22 ± 0.19^{A}	–	–	0.015
D	$3.13 \pm 0.18^{a,B}$	$2.91 \pm 0.01^{a,B}$	$3.11 \pm 0.02^{a,B}$	
OD + D	$2.14 \pm 0.06^{a,A}$	$2.34 \pm 0.03^{b,A}$	$2.39 \pm 0.05^{b,A}$	
FD	$3.07 \pm 0.03^{a,B}$	$3.17 \pm 0.13^{a,b,C}$	$3.31 \pm 0.06^{b,C}$	
Protein (g protein/100 g dry weight)				
OD	7.32 ± 0.12^{A}	–	–	0.014
D	$8.43 \pm 0.04^{a,B}$	$8.35 \pm 0.05^{a,B}$	$8.43 \pm 0.03^{a,B}$	
OD + D	$7.00 \pm 0.46^{a,A}$	$7.42 \pm 0.10^{a,A}$	$7.52 \pm 0.04^{a,A}$	
FD	$8.52 \pm 0.04^{a,B}$	$8.39 \pm 0.05^{a,B}$	$8.42 \pm 0.08^{a,B}$	
NDF (g NDF/100 g dry weight)				
OD	$18.10 \pm 0.42^{B,C}$	–	–	<0.001
D	$17.25 \pm 0.24^{a,B}$	$21.81 \pm 0.15^{b,B}$	$25.21 \pm 0.24^{c,C}$	
OD + D	$19.21 \pm 0.17^{b,C}$	$21.75 \pm 1.37^{c,B}$	$16.27 \pm 0.18^{a,B}$	
FD	$12.06 \pm 1.31^{a,b,A}$	$13.81 \pm 0.63^{b,A}$	$11.37 \pm 0.59^{a,A}$	
ADF (g ADF/100 g dry weight)				
OD	2.85 ± 0.11^{A}	–	–	0.014
D	$3.67 \pm 0.15^{a,B}$	$3.51 \pm 0.15^{a,A}$	$3.71 \pm 0.03^{a,C}$	
OD + D	$3.24 \pm 0.26^{a,A,B}$	$3.22 \pm 0.32^{a,A}$	$2.79 \pm 0.07^{a,A}$	
FD	$3.52 \pm 0.11^{c,B}$	$3.28 \pm 0.06^{b,A}$	$3.04 \pm 0.05^{a,B}$	

Mean ± SD. Different small letter (a–c) superscripts on the same row are significantly different ($p < 0.05$). Different capital letter (A–C) superscripts on the same column are significantly different ($p < 0.05$)

Nutritional composition

The parameters analysed for the four dehydration methods are described in Table 1, for 0, 30 and 60 days. Regarding fat content, all values were low, as expected, ranging from 2.22 g/100 g in OD samples to 3.13 g/100 g for D, all on a dry weight basis. These results are in accordance with the bibliography (0.49–4.0 g fat/100 g dry weight) [18, 22–24]. Significant differences were observed between methods, particularly between the FD and D samples on one side, and the OD and OD + D on the other, because the mass increase induced by sucrose on the OD treatments reduced the relative proportion of the remaining components, therefore, with lower fat content on a dry basis. Partial fat output to the medium during osmotic dehydration process can also be considered, due to cell walls breakage caused by the high osmotic pressure [25]. Along storage, minor variations were observed in the OD + D and FD samples, corresponding to an increase of 12 and 8%, respectively, on a dry basis.

Concerning protein, all initial amounts were in agreement with those published by several authors (4.3–10.87 g protein/100 g dry weight) [18, 22–24, 26]. Nevertheless, significant differences between treatments were found, being again the lowest values obtained by the OD and OD + D methods, as expected. Moreover, no significant differences on the crude protein content were observed along storage time, indicating that this parameter is highly stable.

Concerning fibres, the acid detergent fibre (ADF) values ranged from 2.85 g/100 g (OD) to 3.67 g/100 g (D), while the neutral detergent fibre (NDF) contents varied from 12.06 g/100 g (FD) to 19.21 g/100 g (OD + D), all on a dry weight basis. These values are similar to those obtained by Pereira-Lorenzo et al. [23] (2.3–4.5 g ADF/100 g dry weight and 9.4–28.5 g NDF/100 g dry weight) and Borges et al. [18] (1.89–3.15 g ADF/100 g dry weight and 13.8–24.4 g NDF/100 g dry weight) for raw chestnuts. Both ADF and NDF contents showed some variations along the storage time, without any particular pattern. When comparing all dehydration methods, FD originated samples consistently with lower NDF content, while OD was the method that produced the samples with the lowest value of ADF. The reduced amount of NDF could be attributed to an increase in the indigestible fibre contents, not evaluated in this work, induced by structural changes in the matrix due to the freeze-drying process itself, needing this fact to be further explored in the future.

In general, both D and FD methods, where chestnuts are preserved by water loss, presented a similar composition, exception made for the NDF, as mentioned. In opposition, both dehydration methods (OD and OD + D) were

Table 2 Fatty acids composition along storage time for Longal variety

Parameters	Storage time						p
	0 days	7 days	15 days	30 days	45 days	60 days	Treatment × time
SFA (%)							
OD	20.0 ± 0.4^{B}	–	–	–	–	–	0.012
D	$18.8 \pm 0.7^{a,A,B}$	$18.5 \pm 0.1^{a,A}$	$19.4 \pm 1.0^{a,A}$	$19.4 \pm 0.7^{a,A}$	$19.4 \pm 0.8^{a,A}$	$18.9 \pm 0.1^{a,A}$	
OD + D	$19.9 \pm 0.6^{a,B}$	$19.6 \pm 0.4^{a,B}$	$18.8 \pm 1.2^{a,A}$	$19.4 \pm 0.5^{a,A}$	$19.6 \pm 0.5^{a,A}$	$19.7 \pm 0.2^{a,B}$	
FD	$17.8 \pm 0.4^{a,A}$	$19.6 \pm 0.1^{b,c,B}$	$19.0 \pm 0.6^{b,c,A}$	$18.8 \pm 0.1^{b,A}$	$19.8 \pm 0.3^{c,A}$	$19.0 \pm 0.2^{b,c,A}$	
C16:0 (%)							
OD	16.9 ± 0.4^{A}	–	–	–	–	–	0.271
D	$15.1 \pm 1.2^{a,A}$	$15.3 \pm 0.4^{a,A}$	$16.2 \pm 1.2^{a,A}$	$16.1 \pm 0.5^{a,A}$	$15.9 \pm 0.3^{a,A}$	$15.9 \pm 0.4^{a,A}$	
OD + D	$16.9 \pm 0.6^{a,A}$	$16.4 \pm 0.2^{a,B}$	$16.1 \pm 1.0^{a,A}$	$16.5 \pm 0.4^{a,A}$	$16.8 \pm 0.5^{a,A}$	$16.6 \pm 0.4^{a,A}$	
FD	$15.1 \pm 0.6^{a,A}$	$15.8 \pm 0.2^{a,b,A,B}$	$15.8 \pm 0.5^{a,b,A}$	$16.2 \pm 0.2^{b,A}$	$16.0 \pm 0.4^{a,b,A}$	$16.1 \pm 0.1^{a,b,A}$	
C18:0 (%)							
OD	1.81 ± 0.07^{B}	–	–	–	–	–	<0.001
D	$1.78 \pm 0.09^{a,B}$	$1.64 \pm 0.08^{a,A}$	$1.83 \pm 0.18^{a,B}$	$1.93 \pm 0.15^{a,B}$	$1.69 \pm 0.11^{a,A}$	$1.66 \pm 0.14^{a,A}$	
OD + D	$1.73 \pm 0.05^{a,b,B}$	$1.60 \pm 0.08^{a,b,A}$	$1.49 \pm 0.07^{a,A}$	$1.67 \pm 0.17^{a,b,A,B}$	$1.55 \pm 0.09^{a,b,A}$	$1.82 \pm 0.13^{b,A}$	
FD	$1.39 \pm 0.02^{a,A}$	$2.28 \pm 0.11^{c,B}$	$1.74 \pm 0.04^{b,A,B}$	$1.43 \pm 0.11^{a,A}$	$2.36 \pm 0.06^{c,B}$	$1.69 \pm 0.11^{b,A}$	
MUFA (%)							
OD	$28.0 \pm 0.4^{A,B}$	–	–	–	–	–	<0.001
D	$29.9 \pm 1.1^{a,B}$	$29.7 \pm 0.1^{a,C}$	$28.5 \pm 0.2^{a,A,B}$	$28.4 \pm 0.2^{a,A}$	$29.9 \pm 0.2^{a,A}$	$28.8 \pm 0.9^{a,A}$	
OD + D	$27.5 \pm 1.0^{a,A}$	$27.2 \pm 0.4^{a,A}$	$26.5 \pm 2.1^{a,A}$	$27.9 \pm 0.2^{a,A}$	$28.9 \pm 0.4^{a,A}$	$28.1 \pm 0.4^{a,A}$	
FD	$29.5 \pm 0.8^{a,b,c,A,B}$	$28.3 \pm 0.2^{a,B}$	$30.9 \pm 1.5^{c,B}$	$29.2 \pm 0.3^{a,b,c,B}$	$28.6 \pm 0.8^{a,b,A}$	$30.4 \pm 0.3^{b,c,B}$	
C18:1 (%)							
OD	$26.5 \pm 0.2^{A,B}$	–	–	–	–	–	<0.001
D	$28.4 \pm 1.1^{a,B}$	$28.2 \pm 0.2^{a,C}$	$27.0 \pm 0.2^{a,A,B}$	$26.8 \pm 0.2^{a,A}$	$28.5 \pm 0.2^{a,A}$	$27.4 \pm 1.0^{a,A,B}$	
OD + D	$26.1 \pm 0.8^{a,A}$	$25.7 \pm 0.3^{a,A}$	$25.0 \pm 1.9^{a,A}$	$26.4 \pm 0.2^{a,A}$	$27.4 \pm 0.4^{a,A}$	$26.4 \pm 0.5^{a,A}$	
FD	$27.9 \pm 0.9^{a,b,A,B}$	$26.9 \pm 0.3^{a,B}$	$29.5 \pm 1.6^{b,B}$	$27.7 \pm 0.4^{a,b,B}$	$27.2 \pm 1.0^{a,b,A}$	$29.0 \pm 0.3^{a,b,B}$	
PUFA (%)							
OD	49.1 ± 0.4^{A}	–	–	–	–	–	0.012
D	$47.8 \pm 2.2^{a,A}$	$48.9 \pm 1.5^{a,A}$	$48.2 \pm 0.9^{a,A}$	$48.7 \pm 0.6^{a,A}$	$48.0 \pm 1.4^{a,A}$	$50.0 \pm 1.2^{a,A}$	
OD + D	$48.4 \pm 1.3^{a,A}$	$49.6 \pm 2.1^{a,A}$	$50.8 \pm 0.4^{a,B}$	$50.6 \pm 0.4^{a,B}$	$49.0 \pm 0.6^{a,A}$	$49.2 \pm 0.3^{a,A}$	
FD	$50.9 \pm 0.5^{c,A}$	$50.6 \pm 0.2^{b,c,A}$	$49.0 \pm 0.5^{a,b,c,A}$	$50.0 \pm 0.3^{a,b,c,B}$	$48.7 \pm 1.5^{a,b,A}$	$48.2 \pm 0.5^{a,A}$	
C18:2 (%)							
OD	43.0 ± 0.3^{A}	–	–	–	–	–	0.013
D	$42.2 \pm 2.0^{a,A}$	$43.2 \pm 1.2^{a,A}$	$42.6 \pm 0.7^{a,A}$	$42.8 \pm 0.6^{a,A}$	$42.5 \pm 1.2^{a,A}$	$44.4 \pm 1.0^{a,A}$	
OD + D	$42.7 \pm 1.0^{a,A}$	$43.5 \pm 2.0^{a,A}$	$44.7 \pm 0.4^{a,B}$	$44.4 \pm 0.3^{a,B}$	$43.1 \pm 0.5^{a,A}$	$43.3 \pm 0.3^{a,A}$	
FD	$45.0 \pm 0.6^{b,A}$	$44.7 \pm 0.2^{a,b,A}$	$43.6 \pm 0.4^{a,b,A,B}$	$44.2 \pm 0.3^{a,b,B}$	$43.4 \pm 1.4^{a,b,A}$	$42.9 \pm 0.5^{a,A}$	
C18:3 (%)							
OD	5.97 ± 0.11^{A}	–	–	–	–	–	0.267
D	$5.48 \pm 0.39^{a,A}$	$5.66 \pm 0.38^{a,A}$	$5.52 \pm 0.24^{a,A,B}$	$5.77 \pm 0.02^{a,A}$	$5.24 \pm 0.31^{a,A}$	$5.48 \pm 0.28^{a,A,B}$	
OD + D	$5.68 \pm 0.33^{a,A}$	$5.84 \pm 0.34^{a,A}$	$5.95 \pm 0.08^{a,B}$	$6.11 \pm 0.17^{a,B}$	$5.79 \pm 0.07^{a,A}$	$5.79 \pm 0.07^{a,B}$	
FD	$5.72 \pm 0.22^{a,A}$	$5.72 \pm 0.06^{a,A}$	$5.27 \pm 0.39^{a,A}$	$5.73 \pm 0.07^{a,A}$	$5.19 \pm 0.32^{a,A}$	$5.13 \pm 0.08^{a,A}$	

Mean ± SD with different small letter (a–c) superscripts on the same row are significantly different ($p < 0.05$). Mean ± SD with different capital letter (A–C) superscripts on the same column are significantly different ($p < 0.05$)

characterised by a reduction of both crude fat and protein contents, on a dry basis, induced by the increased soluble solids content (data not shown) from sucrose osmotic drying.

Starch, amylose and sugar composition

The results obtained for starch, amylose and free sugar contents along the storage time are detailed in Fig. 2.

Table 3 Vitamin E composition along storage time for Longal variety

Parameter	Storage time						p
	0 days	7 days	15 days	30 days	45 days	60 days	Treatment × time
Total vitamin E (mg tocopherols/100 g dry weight)							
OD	12.4 ± 0.48^{A}	–	–	–	–	–	0.176
D	$20.6 \pm 1.05^{c,B}$	$19.1 \pm 0.37^{b,c,B}$	$18.2 \pm 0.50^{a,b,B}$	$18.4 \pm 0.49^{a,b,B}$	$18.3 \pm 0.80^{a,b,B}$	$16.8 \pm 0.53^{a,B}$	
OD + D	$14.2 \pm 0.42^{b,A}$	$13.8 \pm 0.69^{a,b,A}$	$12.9 \pm 0.51^{a,A}$	$12.9 \pm 0.29^{a,A}$	$12.6 \pm 0.31^{a,A}$	$12.6 \pm 0.46^{a,A}$	
FD	$18.9 \pm 0.80^{b,B}$	$18.0 \pm 0.75^{a,b,B}$	$17.6 \pm 0.23^{a,b,B}$	$17.9 \pm 0.54^{a,b,B}$	$17.8 \pm 0.56^{a,b,B}$	$16.9 \pm 0.74^{a,B}$	
γ-tocopherol (mg tocopherol/100 g dry weight)							
OD	11.7 ± 0.49^{A}	–	–	–	–	–	0.177
D	$19.8 \pm 1.06^{c,B}$	$18.3 \pm 0.40^{b,c,B}$	$17.6 \pm 0.53^{a,b,B}$	$17.7 \pm 0.47^{a,b,B}$	$17.7 \pm 0.77^{a,b,B}$	$16.2 \pm 0.53^{a,B}$	
OD + D	$13.4 \pm 0.38^{b,A}$	$13.2 \pm 0.72^{a,b,A}$	$12.2 \pm 0.50^{a,b,A}$	$12.3 \pm 0.32^{a,b,A}$	$11.9 \pm 0.31^{a,A}$	$12.0 \pm 0.43^{a,A}$	
FD	$18.3 \pm 0.82^{b,B}$	$17.2 \pm 0.81^{a,b,B}$	$16.9 \pm 0.03^{a,b,B}$	$17.2 \pm 0.55^{a,b,B}$	$17.2 \pm 0.60^{a,b,B}$	$16.1 \pm 0.71^{a,B}$	
δ-tocopherol (mg tocopherol/100 g dry weight)							
OD	0.43 ± 0.02^{A}	–	–	–	–	–	0.001
D	$0.54 \pm 0.04^{a,B}$	$0.54 \pm 0.02^{a,B}$	$0.47 \pm 0.04^{a,A,B}$	$0.54 \pm 0.04^{a,B}$	$0.46 \pm 0.03^{a,A}$	$0.48 \pm 0.04^{a,B}$	
OD + D	$0.48 \pm 0.02^{c,A,B}$	$0.42 \pm 0.04^{b,c,A}$	$0.40 \pm 0.04^{a,b,A}$	$0.34 \pm 0.03^{a,A}$	$0.43 \pm 0.01^{b,c,A}$	$0.38 \pm 0.03^{a,b,A}$	
FD	$0.50 \pm 0.02^{a,A,B}$	$0.56 \pm 0.04^{a,B}$	$0.52 \pm 0.03^{a,B}$	$0.51 \pm 0.03^{a,B}$	$0.49 \pm 0.04^{a,A}$	$0.53 \pm 0.03^{a,B}$	
α-tocopherol (mg tocopherol/100 g dry weight)							
OD	0.22 ± 0.01^{B}	–	–	–	–	–	<0.001
D	$0.23 \pm 0.02^{e,B}$	$0.22 \pm 0.02^{d,e,A}$	$0.19 \pm 0.01^{c,d,A,B}$	$0.15 \pm 0.01^{a,b,A}$	$0.13 \pm 0.05^{a,A}$	$0.17 \pm 0.01^{b,c,A}$	
OD + D	$0.25 \pm 0.02^{a,B}$	$0.25 \pm 0.01^{a,A,B}$	$0.23 \pm 0.02^{a,B}$	$0.22 \pm 0.01^{a,B}$	$0.24 \pm 0.01^{a,B}$	$0.22 \pm 0.02^{a,B}$	
FD	$0.17 \pm 0.01^{b,A}$	$0.28 \pm 0.02^{c,B}$	$0.18 \pm 0.01^{b,A}$	$0.20 \pm 0.01^{b,B}$	$0.11 \pm 0.002^{a,A}$	$0.31 \pm 0.002^{c,C}$	

Mean ± SD with different small letter (a–e) superscripts on the same row are significantly different ($p < 0.05$). Mean ± SD with different capital letter (A–C) superscripts on the same column are significantly different ($p < 0.05$)

Concerning starch (Fig. 2a), 80.6 g/100 g dry weight were quantified in the FD samples at time zero, while significantly lower amounts were determined in the OD samples (51.3 g/100 g dry weight), and D ones (50.1 g/100 g dry weight), and only 33.9 g/100 g dry weight for OD + D. These differences were maintained until the 45th day of storage, but at the 60th day no significant differences were observed between D and FD, with 68.6 g/100 g and 74.0 g/100 g, respectively. Being starch contents inversely associated with the use of temperature in the several methods tested, it could be associated with the inactivation of the enzymes responsible for starch hydrolysis by high temperatures or to an increase in the resistant starch fraction, not quantified in the present study [27, 28]. Also, the slight increase on the starch content along storage could be an indicator of a partial recovery of starch properties.

Regarding amylose (Fig. 2b), expressed on a starch basis, no significant differences were found between methods, with the exception of D that presented slightly higher values (17.2 g/100 g), followed by OD + D (13.9 g/100 g), against 11.1 g/100 g and 10.50 g/100 g for OD and FD, respectively. Again, these differences could be related to the temperatures used, increasing the relative proportion of amylose in the starch due to the starch reduction observed, rather than by a true increase in the amylose amounts. This is consistent with Attanasio et al. [5] and Correia and Beirão-da-Costa [29] when comparing raw with dried chestnuts. During the storage period, the differences between methods remained reduced. At the end of storage (60 days), a decrease of 31 and 22% on amylose content in the starch was observed on the D and OD + D, respectively, consistent with the starch increase observed, while for FD no significant difference was found between 0 and 60 days of storage, associated with unaltered starch and amylose properties. These results showed that FD was the technology that preserved better the starch and amylose structures.

Concerning sucrose (Fig. 2c), OD and OD + D methods presented significantly higher contents than D and FD, respectively, with 35.4 g/100 g and 32.3 g/100 g dry weight, against 15.7 g/100 g, and 18.1 g/100 g, all on a dry basis, remaining almost constant during all storage period. The highest values determined on OD and OD + D samples were expected, due to the use of a sucrose solution as osmotic medium.

In relation to glucose (Fig. 2d), no significant differences were observed between dehydration methods, with the exception of D that presented the highest amounts

Table 4 Sensory analysis along storage time for Longal variety

Parameter	Storage time						p
	0 days	7 days	15 days	30 days	45 days	60 days	Treatment × time
Sweetness							
OD	4.1 ± 0.6^{B}	–	–	–	–	–	0.003
D	$4.0 \pm 0.6^{a,B}$	$4.1 \pm 0.6^{a,b,B}$	$3.4 \pm 0.4^{a,A}$	$4.9 \pm 0.6^{b,B}$	$3.8 \pm 0.4^{a,A}$	$3.7 \pm 0.6^{a,A}$	
OD + D	$4.7 \pm 0.7^{a,B}$	$5.4 \pm 0.8^{a,C}$	$5.7 \pm 0.8^{a,B}$	$5.7 \pm 0.8^{a,B}$	$5.4 \pm 0.8^{a,B}$	$5.6 \pm 0.8^{a,B}$	
FD	$2.2 \pm 0.4^{a,A}$	$3.0 \pm 0.5^{a,b,A}$	$3.8 \pm 0.5^{c,A}$	$3.8 \pm 0.6^{c,A}$	$3.7 \pm 0.5^{b,c,A}$	$3.4 \pm 0.4^{a,b,c,A}$	
Hardness							
OD	$6.2 \pm 0.7^{A,B}$	–	–	–	–	–	0.812
D	$7.4 \pm 1.1^{a,B,C}$	$7.7 \pm 1.1^{a,B}$	$7.9 \pm 1.2^{a,B}$	$7.8 \pm 1.1^{a,B}$	$8.1 \pm 1.2^{a,B}$	$8.2 \pm 1.2^{a,B}$	
OD + D	$8.1 \pm 1.2^{a,C}$	$8.3 \pm 1.1^{a,B}$	$8.3 \pm 1.2^{a,B}$	$8.5 \pm 1.0^{a,B}$	$8.4 \pm 0.8^{a,B}$	$8.5 \pm 1.0^{a,B}$	
FD	$6.0 \pm 0.9^{a,b,A}$	$5.9 \pm 0.9^{a,b,A}$	$5.7 \pm 0.8^{a,b,A}$	$5.4 \pm 0.7^{a,A}$	$5.9 \pm 0.5^{a,b,A}$	$6.7 \pm 0.9^{b,A}$	
Crispness							
OD	4.9 ± 0.6A	–	–	–	–	–	0.009
D	$7.2 \pm 0.9^{b,B}$	$6.9 \pm 1.1^{b,A}$	$5.4 \pm 0.6^{a,A}$	$6.2 \pm 0.8^{a,b,A}$	$6.8 \pm 1.0^{a,b,A}$	$6.0 \pm 0.8^{a,b,A}$	
OD + D	$6.9 \pm 1.0^{a,B}$	$7.0 \pm 1.0^{a,A}$	$7.4 \pm 1.1^{a,B}$	$7.5 \pm 1.0^{a,B}$	$7.4 \pm 1.2^{a,A}$	$8.0 \pm 1.1^{a,B}$	
FD	$6.3 \pm 0.8^{a,B}$	$7.3 \pm 1.0^{a,A}$	$7.1 \pm 1.1^{a,B}$	$7.1 \pm 1.1^{a,A,B}$	$7.0 \pm 1.1^{a,A}$	$7.3 \pm 1.1^{a,A,B}$	
Freshness							
OD	6.7 ± 0.9^{B}	–	–	–	–	–	0.021
D	$5.1 \pm 0.8^{b,A}$	$5.2 \pm 0.6^{b,A}$	$4.3 \pm 0.6^{a,b,A}$	$4.1 \pm 0.6^{a,A}$	$4.2 \pm 0.5^{a,A}$	$4.2 \pm 0.5^{a,A}$	
OD + D	$6.7 \pm 1.0^{b,B}$	$6.7 \pm 0.7^{b,B}$	$6.4 \pm 1.1^{b,B}$	$6.8 \pm 0.9^{b,B}$	$4.6 \pm 0.5^{a,A,B}$	$4.9 \pm 0.5^{a,B}$	
FD	$6.7 \pm 1.0^{a,b,B}$	$6.8 \pm 1.0^{b,B}$	$6.2 \pm 1.0^{a,b,B}$	$5.8 \pm 0.8^{a,b,B}$	$5.4 \pm 0.8^{a,B}$	$5.4 \pm 0.6^{a,B}$	
Overall acceptance							
OD	7.4 ± 0.9^{B}	–	–	–	–	–	0.226
D	$5.6 \pm 0.8^{c,A}$	$6.1 \pm 0.8^{c,A}$	$5.4 \pm 0.7^{b,c,A}$	$3.9 \pm 0.5^{a,A}$	$4.2 \pm 0.6^{a,A}$	$4.3 \pm 0.6^{a,b,A}$	
OD + D	$7.4 \pm 1.1^{b,B}$	$7.4 \pm 0.9^{b,B}$	$7.1 \pm 1.0^{b,B}$	$6.9 \pm 1.1^{a,b,B}$	$6.1 \pm 0.8^{a,b,B}$	$5.6 \pm 0.8^{a,B}$	
FD	$7.2 \pm 1.0^{a,b,B}$	$7.6 \pm 1.0^{b,B}$	$7.4 \pm 0.9^{b,B}$	$7.0 \pm 1.1^{a,b,B}$	$6.8 \pm 1.0^{a,b,B}$	$5.8 \pm 0.9^{a,B}$	

Mean ± SD with different small letter (a–c) superscripts on the same row are significantly different ($p < 0.05$). Mean ± SD with different capital letter (A–C) superscripts on the same column are significantly different ($p < 0.05$)

(0.62 g/100 g dry weight, against 0.35 g/100 g, 0.36 g/100 g and 0.34 g/100 g dry weight, for OD, OD + D and FD, respectively). These differences might be due to the temperature used on the D method, near to the optimum for some enzymes (between 55 and 60 °C) mainly, α-amylase, β-amylase and glucoamylase [30]. These enzymes might partially hydrolyse starch, releasing glucose, explaining the highest glucose content in the hot-air dried samples. Temperature-induced hydrolysis is not to be expected as it requires higher temperatures than 50 °C. Along the storage period, a small increase on glucose content was observed in the D and FD samples, consistent with probable enzyme activity, while it seemed to be refrained by the osmotic pressure increase in the OD + D samples, with constant glucose amounts through storage, and therefore absence of sucrose hydrolysis as well.

Concerning fructose (Fig. 2e), it was interesting to observe a similar behaviour to glucose, being the highest value of fructose obtained for the D method (0.70 g/100 g dry weight) against the other methods (0.32 g/100 g, 0.36 g/100 g and 0.20 g/100 g, for OD, OD + D and FD, respectively). The value determined for FD was in agreement with those published by Künsch et al. [31] (0.37 to 0.69 g/100 g dry matter) and Barreira et al. [32] (0.57 to 5.32 g/100 g dry matter) for raw chestnuts. Regarding storage, an increasing trend was perceived for the D method that might result from natural sucrose hydrolysis, but it is not consistent with the OD + D samples, with higher sucrose content but absence of hydrolysis (glucose and fructose contents remained constant with time). Also, no increase was observed in the FD samples. Thus, this phenomenon could probably be explained by more adequate conditions for enzymatic activity in the D samples, than in the FD or OD + D ones.

Regarding the raffinose content (Fig. 2f), no significant differences were observed between dehydration methods and only slight variations were stated along the storage period.

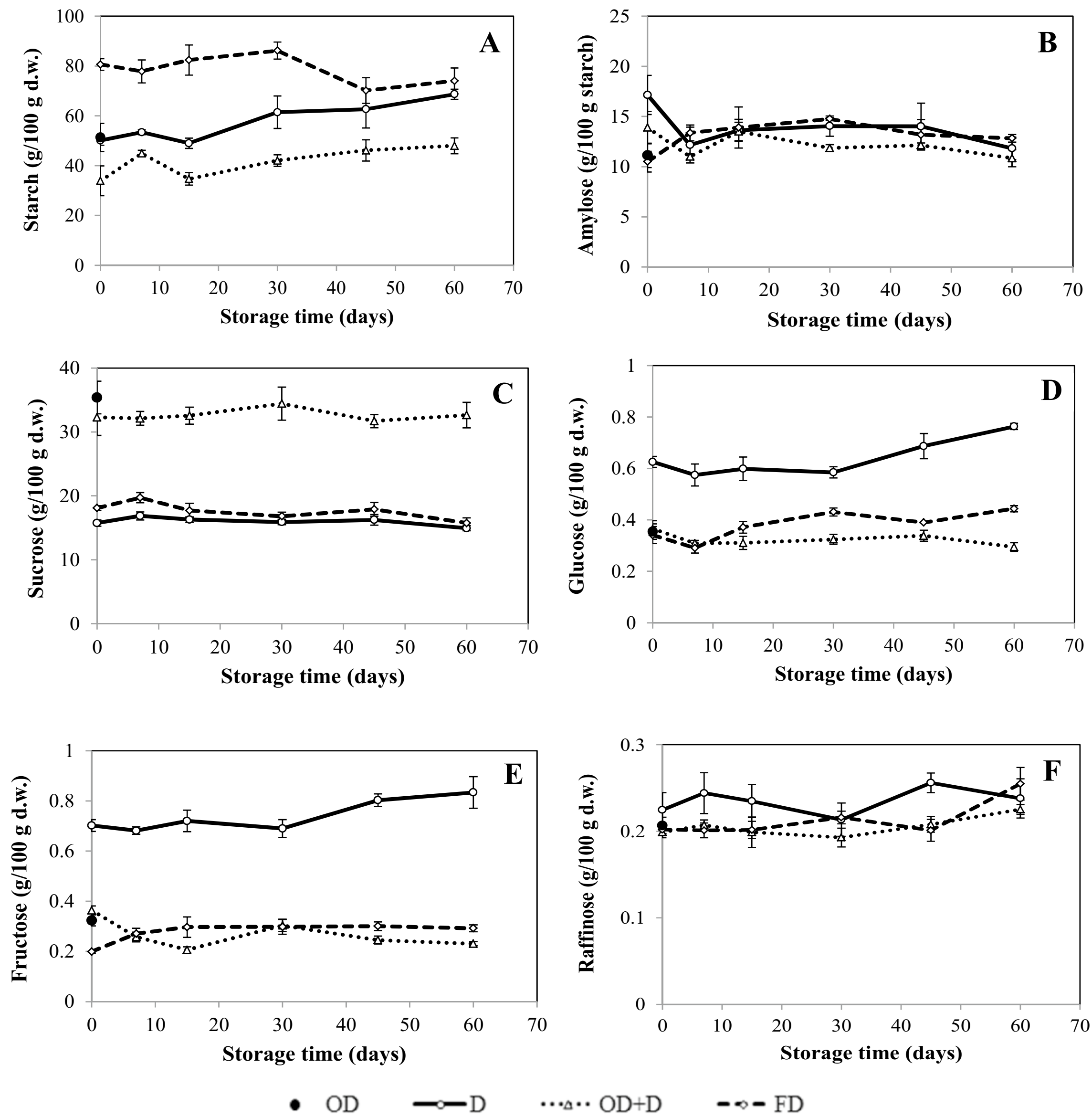

Fig. 2 Sugar composition along storage time. **a** starch; **b** amylose; **c** sucrose; **d** glucose; **e** fructose; **f** raffinose contents

Organic acids composition

The results obtained for the organic acid contents (malic, ascorbic, citric and fumaric acids) are detailed in Fig. 3. Regarding malic acid, the main component, significant differences were found between dehydration methods at time zero, with a mean of 954 ± 72 mg/100 g for D, followed by 802 ± 40 mg/100 g for FD, 430 ± 38 mg/100 g for OD + D, and finally 320 ± 30 mg/100 g for OD, all on a dry basis. These results showed that osmotic dehydration induced higher losses of malic acid than the other methods, probably from lixiviation to the aqueous sucrose solution. Some of these values were slightly higher than those reported by Gonçalves et al. [33] (147 to 532 mg/100 g dry weight) and Neri et al. [34] (152 to 330 mg/100 g dry weight) for raw chestnut fruits. Concerning the effect of storage, even though some fluctuation was observed for all methods, a decrease trend was stated when comparing the amounts at 0 and 60 days of storage (Fig. 3a), smaller in the D method (−28%), and higher in the OD + D (−42%), suggesting that, despite the initial differences, none of the three processes was able to avoid malic acid degradation.

In relation to ascorbic acid, significant differences were found between the four dehydration methods, with higher values in the FD method (Fig. 3b), being the method that better preserved ascorbic acid in the chestnut slices, and therefore has potentially the highest nutritional score. The ascorbic

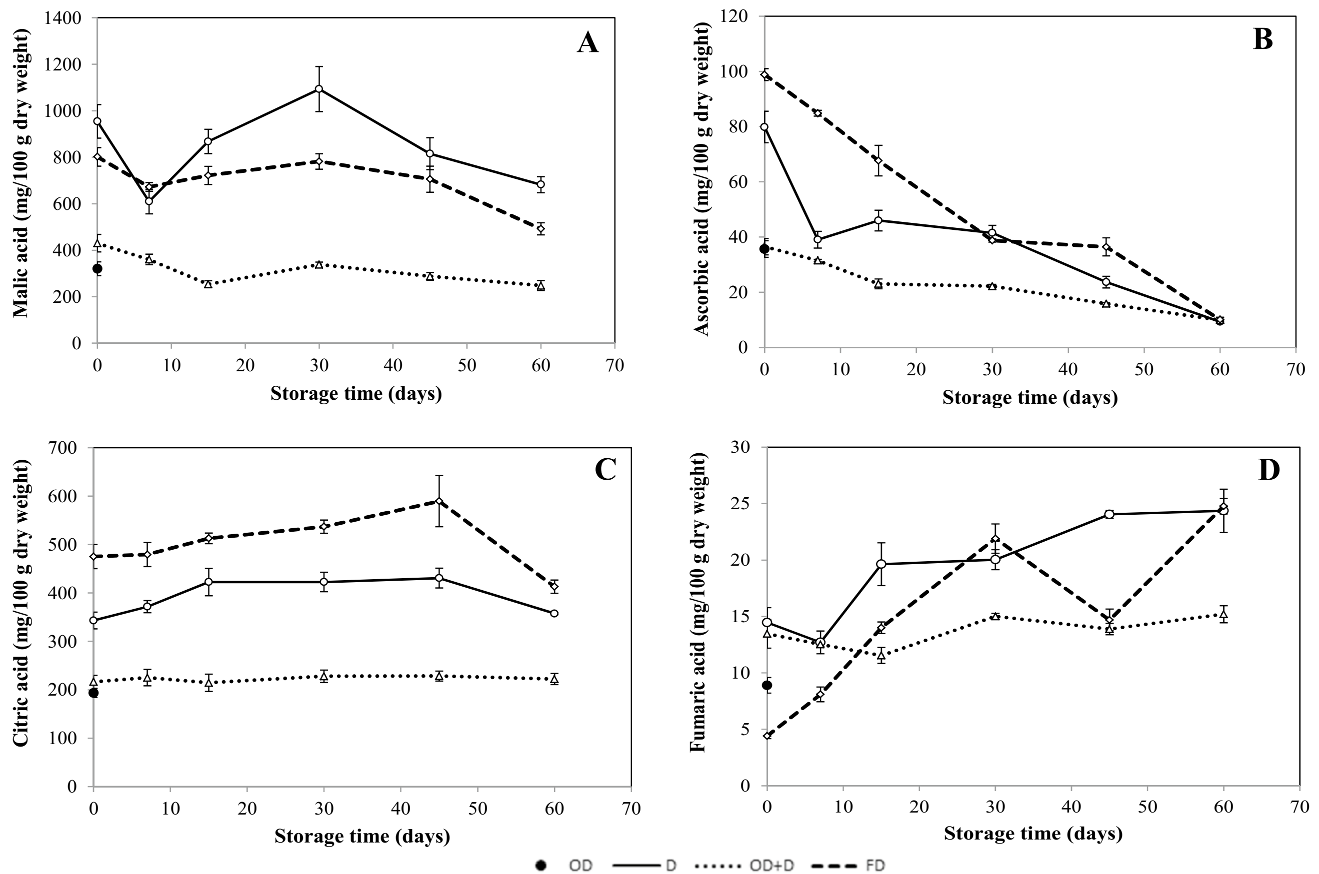

Fig. 3 Organic acids composition along storage time. **a** malic acid; **b** ascorbic acid; **c** citric acid; **d** fumaric acid contents

acid initial content varied from 99 ± 2 mg/100 g dry weight for FD, to 80 ± 6 mg/100 g dry weight for D, and 36 ± 3 mg/100 g dry weight for both OD and OD + D, showing again that osmotic dehydration was the process that most affected this compound. Germer et al. [35] also verified losses on ascorbic acid during OD of papaya, justifying by chemical deterioration and diffusion of this compound from the fruit to the solution. Our values of FD were in accordance with Neri et al. [34] (28 to 128 mg/100 g dry weight) but higher than those reported by Barros et al. [36] (40.0 to 69.3 mg/100 g dry weight) and Ribeiro et al. [37] (4.52 to 16.4 mg/100 g dry weight) for raw chestnuts, probably associated with the high freshness of our samples and adequate preservation by FD. Concerning the storage period, a decreasing trend was observed for all dehydration methods, all reaching a similar and almost residual value at the end of storage (10 mg/100 g dry weight). These losses could probably be due to the oxidation of this compound, induced by the oxygen present in the storage bags, or by enzymatic degradation (ascorbate oxidase), as well as by reaction with other sample components. In fact, no modified atmosphere packaging was applied, being an interesting topic to be studied in the future.

Concerning citric acid (Fig. 3c), smaller variations on the content of this compound were observed along storage, suggesting that citric acid seemed to be more resistant than the other organic acids. Nevertheless, the effect of the dehydration methods was more important than storage time, being again FD the method with the highest values (475 to 413 mg/100 g dry weight for 0 and 60 days of storage, respectively), followed by D (343 to 357 mg/100 g dry weight for 0 and 60 days of storage, respectively), and OD + D (216 to 222 mg/100 g dry weight for 0 and 60 days of storage, respectively). The low values of citric acid determined for the OD and OD + D, indicated that osmotic dehydration had probably cause the migration of this compound to the osmotic solution or its degradation, as previously discussed for the other organic acids.

The results for fumaric acid, presented in Fig. 3d, showed an opposite pattern to that observed in the previous compounds. At the beginning (0 days of storage), no significant differences were observed between D and OD + D method (14.5 ± 1.3 mg/100 g dry weight and 13.5 ± 1.3 mg/100 g dry weight,

respectively), with higher amounts than those observed for FD (4.41 ± 0.23 mg/100 g dry weight), or OD (8.90 ± 0.69 mg/100 g dry weight). Some authors have referred that during heat processing (evaporation, pasteurisation and sterilisation) of apple juices, the content of fumaric acid may slightly increase due to malic acid dehydration [38]. This is consistent with the higher initial values for the heated processing samples (D and OD + D). It is also believed that this acid is an important parameter to reveal microbial spoilage or the processing of decayed fruits [39]. Regarding storage period, an increase of this organic acid was verified, indicating probably the occurrence of malic acid dehydration as a decreasing trend of this last compound was observed in the present work (Fig. 3a). In general terms, at the end of storage an increase on fumaric acid content of 13, 68 and 462% were observed for OD + D, D and FD, respectively. In general terms, even though FD was the method that preserved better the organic acids on samples at 0 days of storage, the OD + D method was the one that induced less changes on the organic acid contents of chestnut slices along storage.

Fatty acids composition

The main fatty acids composition of chestnut slices is present in Table 2. Globally, PUFA represented the highest fraction, ranging from 47.8% in D to 50.9% in FD, with the main contribution of linoleic and α-linolenic acids, essential fatty acids. MUFA represented the second main class, with similar relative amounts in the OD and OD + D fat (28%), slightly lower than 30% presented by the FD or D samples. SFA were present in lower amounts, with 17.8% in the FD samples, followed by the D ones (18.8%), and then with OD and OD + D, both with 20%. These amounts are consistent with literature data for chestnut (SFA 14.1–24.6%; MUFA 21.7–40.8%; PUFA 41.5–60.1%) [40–42].

In general terms, the values determined for the four dehydration methods were similar between them; however, in some situations significant differences were observed. Along storage and after 60 days, a slight alteration on the fatty acids proportions was observed, particularly in the FD ones, where a significant PUFA reduction was observed. This decrease was mainly due to losses on the main PUFA, namely linoleic acid. Therefore, although at time zero FD preserved better the PUFA content, along drying it was the method that induced higher oxidation. This increased oxidation, already observed in the ascorbic acid contents, can be associated with the chestnut physical structure of the FD samples, with a higher exposition surface to air.

Vitamin E composition

The results obtained for vitamin E, directly involved in the PUFA protection, are shown in Table 3. Total vitamin E amounts ranges from 12.4 to 20.6 mg/100 g dry weight. Interestingly, the vitamin E amounts are directly correlated with the fat content, with lower amounts in the OD and OD + D samples, indicating that, independently of the fat content, the potential protection granted by Vitamin E was similar between all samples. Being vitamin E a lipophilic compound and as a decrease of crude fat was observed as the result of output of fat to the osmotic medium due to the breakage of cell walls caused by the high osmotic pressure [25] and/or high contact time, probably the vitamin E also went out with the crude fat.

The major component was γ-tocopherol with 11.7, 19.8, 13.4 and 18.3 mg/100 g dry weight for OD, D, OD + D and FD, respectively, at 0 days of storage, with significant differences between them. Higher values of γ-tocopherol were obtained for FD and D methods, showing again that the osmotic dehydration could probably affect more the γ-tocopherol content than the other methods. Along storage, for γ-tocopherol no significant differences were observed between D and FD, indicating that both processes induced similar modifications on this vitamer. Concerning storage period, a decreasing trend on γ-tocopherol content was observed for all methods, being found losses equal to 18, 10 and 12% (by dry weight) for D, OD + D and FD, respectively. As no fat decrease was observed along storage, it can only indicate that a true vitamin E loss occurred during storage.

For δ-tocopherol, the second most abundant vitamer, significant differences at time zero were just found between the OD and D (0.43 and 0.54 mg/100 g dry weight, respectively), with the other samples presenting intermediate amounts. Along storage, small variations were stated; however, no significant differences on δ-tocopherol content were observed for D and FD after 60 days of storage when compared with the beginning, while for OD + D a small decrease (21%) was verified.

In terms of α-tocopherol, no significant differences were found between the dehydration methods at the beginning (0 days of storage) with the exception of FD, with lower amounts. Along storage, even though some fluctuation on α-tocopherol content was observed, its range was small, varying between 0.11 and 0.31 mg/100 g dry weight.

Principal component analysis (PCA) to the chemical composition data

After performing a PCA (Fig. 4) to the chemical composition results (A = nutritional composition, B = sugars, C = organic acids and D = lipid components), two

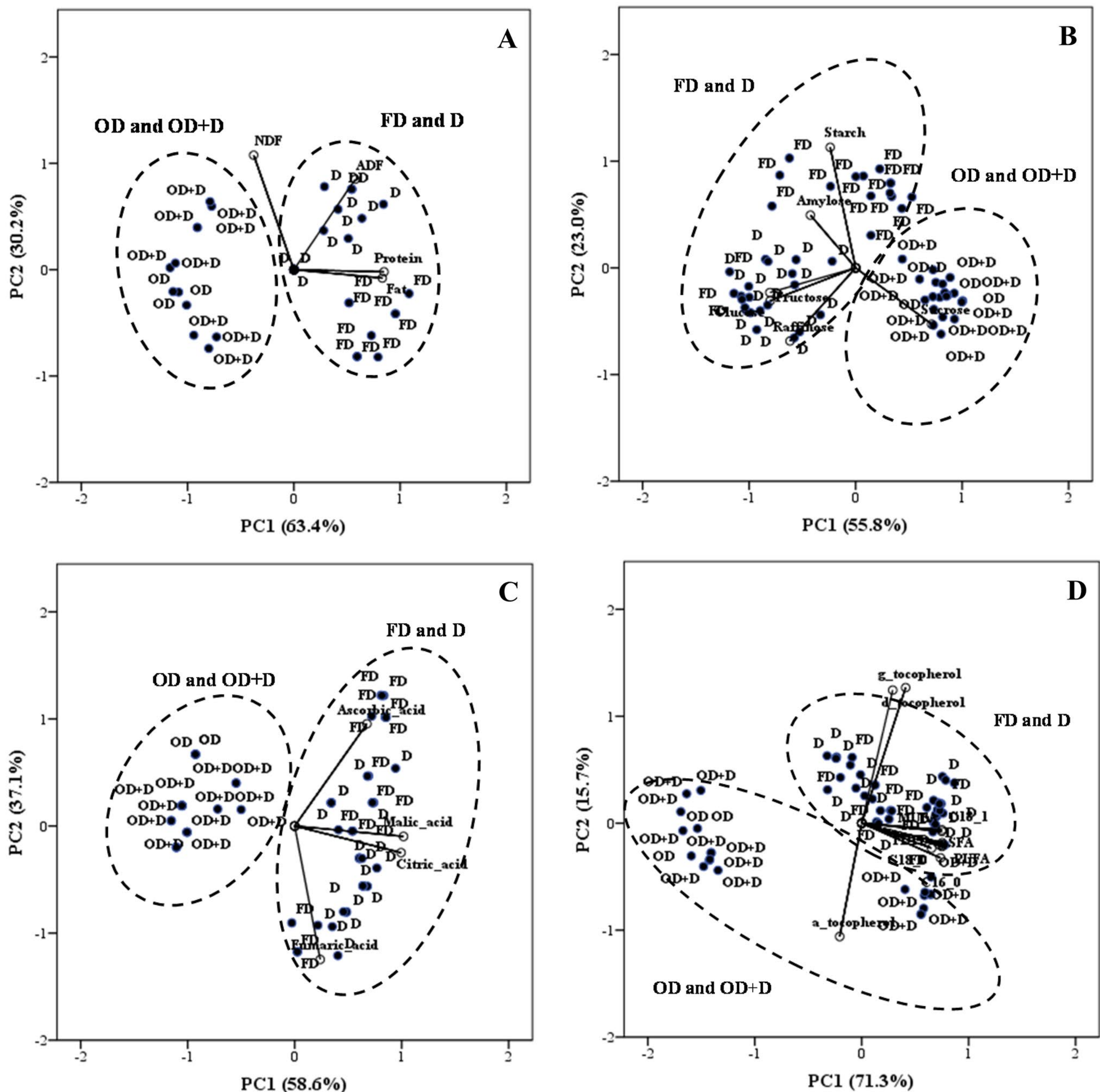

Fig. 4 Loadings and scores plots resulting from the Principal Component Analysis: **a** nutritional composition; **b** starch, amylose and sugars composition; **c** organic acids composition; **d** lipid profile of the chestnuts snack slices

principal components were extracted (PC1 and PC2) that accounted for 87.0 to 95.7% of the total variation. According to the PCA scores plots, two different groups were always clearly differentiated from each other, namely, OD + (OD + D) (Group I) and D + FD (Group II) that differed on all the components analysed. In opposition, storage time was not so well differentiated (data not shown). These results indicated that the dehydration method applied had a more important role than the storage period on the chemical composition of chestnut slices.

Sensory analysis

The sensory scores are presented in Table 4. Sweetness, hardness, crispness, freshness and overall acceptance of the different samples were determined by a panel of 11 semi-trained judges. Regarding sweetness, at day = 0, OD, D

and OD + D methods were classified similarly (4.1, 4.0 and 4.7), while a significantly lower score was attributed to the FD samples (2.9). In relation to storage time, no significant differences were observed between 0 and 60 days of storage for all dehydration methods, indicating that sweetness feeling remained constant along storage.

Concerning hardness, some significant differences were observed between methods at the beginning, being the lowest value of hardness always found for the freeze-dried sample. Moreover, no significant differences were observed along the storage time, suggesting that this parameter did not change along storage.

In relation to crispness, at the beginning of the storage (0 days), the OD method was the one that presented the lowest value (4.9), due to the increased water content, while all other methods seemed to have similar high values for this parameter (7.2 for D, 6.9 for OD + D, and 6.3 for FD). Small variations were observed along storage time; however, no significant differences were found between 0 and 60 days of storage for all methods.

Freshness is one important parameter measured by the judges. At the beginning, a reasonable level of freshness was observed after the application of the four dehydration methods, having the lowest value been recorded for the D method (5.1). On the other hand, the judges did not find significant differences between OD, OD + D and FD, all with 6.7. Along storage, this difference was maintained, being the lowest value always observed for D. Nevertheless, at the end, a decrease on freshness was observed on all samples, with relative losses of 18, 27 and 20% for D, OD + D and FD, respectively. Nevertheless, for FD no significant differences were found between 0 and 60 days of storage, being the method that kept the freshness of chestnut slices longer. On contrary, D was only able to maintain the initial freshness until 15 days and OD + D until 30 days.

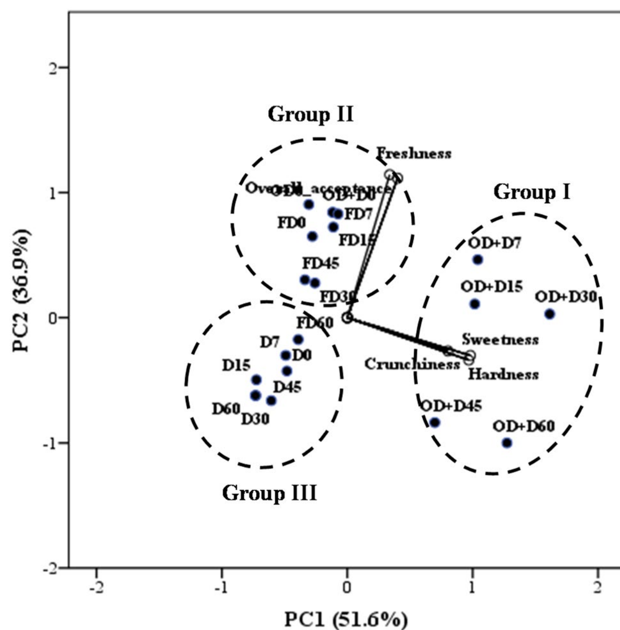

Fig. 5 Loadings and scores plot resulting from the Principal Component Analysis to the sensory data

After application of the four dehydration technologies (0 days), a good overall acceptance was verified for all methods (7.4, 5.6, 7.4 and 7.2 for OD, D, OD + D and FD, respectively). No significant differences were observed between methods at the beginning and also along the storage period, with the exception of D, which always presented the lowest values, showing the lowest overall acceptance. After 7 days of storage, a decreasing trend was observed in the mean values for all dehydration methods. However, no significant differences were observed between 0 and 60 days of storage for FD, showing again to be the method able to maintain the quality of chestnut slices longer, closely followed by OD + D. Nevertheless, as stated before, the freshness of the OD + D sample might be compromised after 30 days of storage.

These results were also stated after performing a PCA to the sensory results (Fig. 5). Two principal components were extracted (PC1 and PC2) that accounted for 88.5% of the total variation. According to the PCA scores plot, three different groups were clearly differentiated from each other, namely: Group I—formed by the OD + D samples after 7 days of storage or longer, corresponding to the sweetest, crunchiest and hardest samples. In particular, the samples of OD + D at 45 and 60 days lost freshness and the overall acceptance decreased; Group II—formed by the FD samples, as well as, the OD and OD + D at the beginning (0 h), corresponding to the freshest and the best score samples in terms of overall acceptance; and Group III—formed by the D samples, as well as, the FD samples at 60 days of storage that were the worst rated in terms of overall acceptance.

Conclusions

In conclusion, the present work showed that OD, D, OD + D and FD had different effects on both chemical and sensory properties of chestnut slices, as well as along storage. Even though FD was the method that represented more closely fresh chestnuts, the sensorial panel attributed lower scores on some physical attributes and significant organic acids losses were detected along storage. Nevertheless, FD was the method that kept the freshness of chestnut slices longer. The chestnut slices obtained by D presented very similar characteristics to the FD except in sensorial scores, being the worst rated process due to the loss of freshness and overall acceptance. Even though, OD + D induced

relative losses on fat, protein and organic acids, due to the relative incorporation of sucrose and/or diffusion of these components, it was the method that showed the most uniform behaviour along storage. Furthermore, the samples of OD + D were well rated in terms of sensorial properties, losing freshness after 30 days. So, the most promising methods to be applied in the future to chestnut slices would be FD and OD + D.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

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