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EFFECT OF DRYING ON COLOR, PROXIMATE COMPOSITION AND DRYING KINETICS OF SLICED CHESTNUTS

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ABSTRACT

In the present work, dried sliced chestnuts (Judia and Longal varieties), product with an increased shelf life, low calorie and gluten-free contents, were prepared. The effect of air convective drying on the drying kinetics, color and proximate composition of sliced chestnuts was evaluated. Even though significant differences in nutritional composition were found between both varieties at the beginning, the drying behaviors were similar; however, Judia dried at a slightly faster rate than Longal. The use of Page, two-term, and modified Henderson and Pabis models fitted well the experimental data (adjusted $R^2 > 0.999$). With drying, slight variations in color were observed for both varieties and only moisture content decreased significantly.

The obtained product retained all chemical composition, and due to the low caloric value (367 kcal/100 g product), low fat and gluten-free contents of chestnut slices, this can be an interesting substitute to other high-calorie snacks available in the market.

PRACTICAL APPLICATIONS

The chestnut fruit is increasingly popular among consumers. The fruit is usually sold fresh or frozen while smaller fruits are generally rejected by industries. So, it is very important to find alternatives to valorize these fruits. Moreover, consumers search for healthy and easy-to-consume food. Chestnut follow these requisites, being a nut with interesting properties due to its low fat content, high levels of starch (sugar of slow absorption) and significant amounts of fibers. Furthermore, it is a gluten-free nut, ideal for celiac patients. On the other hand, the majority of snacks in the market are rich in fat and are made from wheat flour. So, the development of snacks based on chestnut would be innovative. This study intends to provide information on the effect of drying on color, nutritional composition and drying kinetics of sliced chestnut in order to obtain a healthy and low-calorie content snack.

INTRODUCTION

Consumers' search for healthy and easy-to-consume food is increasing. Chestnut follows these requisites, being a nut with interesting properties due to its low fat content, high levels of starch (sugar of slow absorption) and significant amounts of fibers (Borges *et al.* 2008). Furthermore, it is a gluten-free nut, ideal for celiac patients. On the other hand, the majority of snacks in the market are rich in fat and are made from wheat flour (that contains gluten). So, the development of snacks based on chestnut would be innovative and will allow the development of new products to persons with sensitivity to gluten. The production of dried slices of chestnuts emerged as a possible and healthy option, with low-calorie content.

Several studies on hot air drying have been performed in chestnuts, namely on drying kinetics (Moreira *et al.* 2005; Guiné and Fernandes 2006; Cletus and Carson 2008), drying characteristics and energy requirement for dehydration (Koyuncu *et al.* 2004), the effect of drying temperatures on morphological, chemical, thermal and rheological properties in chestnut flours (Correia *et al.* 2009; Correia and Beirão-da-Costa 2012; Moreira *et al.* 2013), the effect of drying followed by rehydration on different properties of chestnuts (Attanasio *et al.* 2004; Moreira *et al.* 2008, 2011) and how starch is affected by different drying methods (Zhang *et al.* 2011).

Until now, most of these studies have been carried out with peeled and unpeeled whole fruits. Only one study using prismatic chestnut samples ($10 \times 10 \times 15$ mm), subjected to convective air drying at 65 ± 0.5C has been performed (Moreira *et al.* 2011). Still, only the chestnut cellular tissue was analyzed with significant changes in cell size as drying process progressed. So, until now few results exist on the role of drying in sliced chestnuts properties. Thus, the aim of our work was to assess the effect of hot-air convective drying in physical and proximate composition of chestnuts cut in slices along drying time in order to analyze the effect of thermal processing on them.

MATERIALS AND METHODS

Plant Material

Two chestnut varieties were used in this study, namely Longal and Judia, the most common in the region. The nuts were acquired directly to chestnut producers of Macedo de Cavaleiros (Longal variety) and Vinhais (Judia variety) at north-east of Portugal (50 kg each variety) in November 2012 and stored in cold chambers (4 ± 1C) (maximum 1 month) until the analyses were carried out.

Drying Experiments

After removing carefully the exterior shell with a knife, chestnuts were sliced with approximately 4–6 mm of thickness (Fig. 1 at 0 h). Then, for fixed time periods (1, 2, 4, 6, 8 and 10 h), around 150 g of chestnut slices were dried in a tray dryer (Armfield, Ringwood, England) at 50C (Fig. 2). This temperature was chosen because it was the maximum allowable by the equipment and it was a common temperature found on other drying studies of fruits (Koyuncu *et al.* 2004; Correia *et al.* 2009; Correia and Beirão-da-Costa 2012). The tray dryer consisted of one fan and an electric heating element (maximum power 3 kW). The hot air passed through the central section of the duct, where the tray with the material to drying is fixed, going out to the atmosphere. The tray was connected to a decimal scale and the data acquisition was recorded in a computer through the Windows Hyperterminal software (Hilgraeve, Monroe, Michigan, USA).

The air velocity was measured with a portable anemometer (Airflow, LCA 6000, Buckinghamshire, England) and kept constant at 1.2 ± 0.1 m/s throughout experiments. The control (fresh chestnuts) and drying samples (1, 2, 4, 6, 8 and 10 h) were frozen and freeze-dried in order to determine their moisture contents and their proximate composition were expressed in dry basis. All drying experiments at each time period were performed in triplicate.

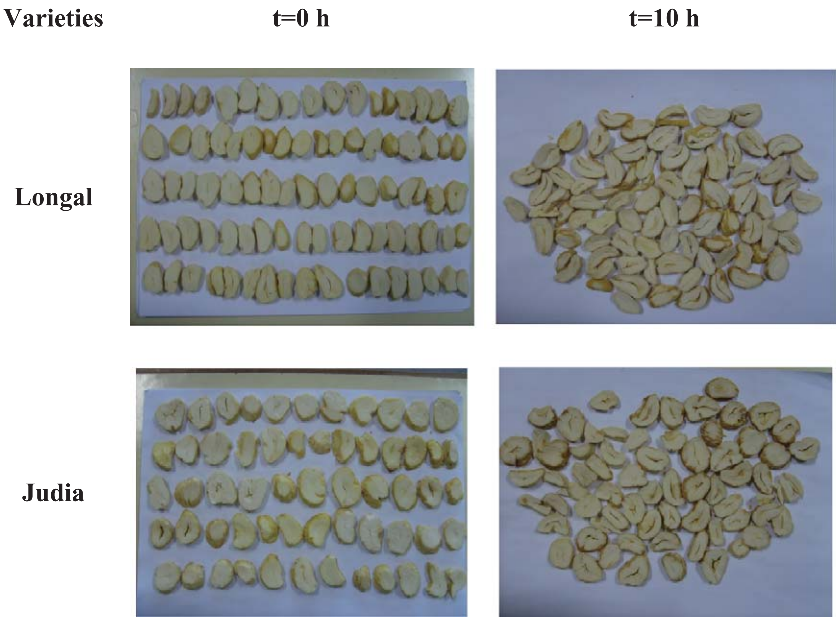

FIG. 1. CHESTNUTS OF LONGAL AND JUDIA VARIETIES AT 0 AND 10 H AFTER DRYING AT 50C

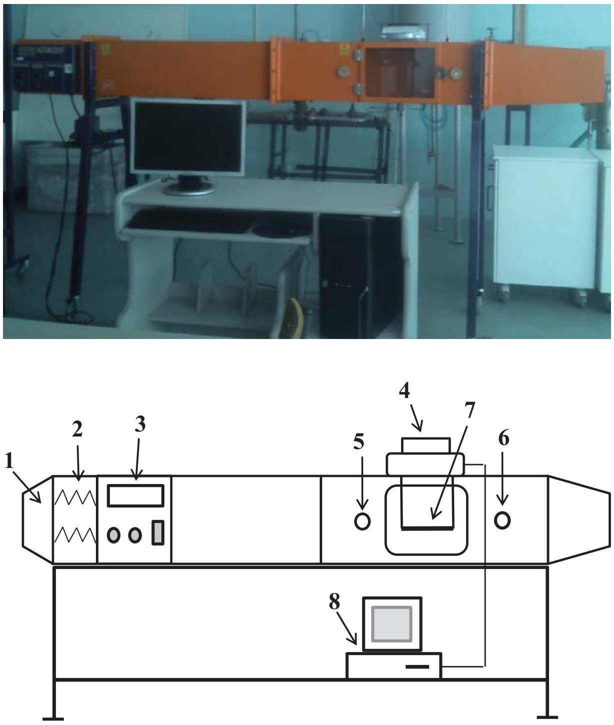

FIG. 2. PHOTOGRAPH AND SCHEMATIC FIGURE OF THE TRAY DRYER (ARMFIELD): FAN (1); HEATER (2); CONTROL PANEL (3); DECIMAL BALANCE (4); TEMPERATURE AND HUMIDITY SENSORS (5) AND (6); TRAY FOR SAMPLES (7); COMPUTER (8)

The drying process was followed by weighting the chestnut slices at regular time intervals (40 s) with an accuracy of ± 0.1 g, being the moisture ratios (MR) determined by Eq. (1).

$$MR = \frac{W - W_e}{W_0 - W_e} \tag{1}$$

where W, W_0 and W_e represent the instantaneous, initial and equilibrium dry basis water contents (kg water/kg dry basis), respectively. W_e was determined as the asymptotic value of the function fit of the experimental points at the final stage of drying.

Several mathematical models were tested to fit the moisture ratio versus time; however, only the three best models are presented, whose equations are shown in Table 1.

The model parameters were determined by SPSS software (Version No. 20.0, IBM Corporation, Armonk, New York, USA) and the suitability of the fits was evaluated by the following parameters:

$$SSE = \sum_{i=1}^{n} \left(y_{\exp,i} - y_{\mathrm{model},i} \right)^2 \tag{2}$$

$$SST = \sum_{i=1}^{n} \left(y_{\exp} - y_{average} \right)^2 \tag{3}$$

$$R^2 = 1 - \frac{SSE}{SST} \tag{4}$$

TABLE 1. DRYING CURVE MODELS AT 50C FOR TWO CHESTNUT VARIETIES

Variety	Page model $MR = \exp(-k \times t^n)$	Two-term model $MR = a \times \exp(-k \times t) + b \times \exp(-g \times t)$	Modified Henderson and Pabis model $MR = a \times \exp(-k \times t) + b \times \exp(-g \times t) + c \times \exp(-h \times t)$
Judia	$k = 0.3727$	$a = 0.115$	$a = 0.8977$
	$n = 0.8973$	$k = 2.566$	$b = 0.5535$
	SSE: 0.02617	$b = 0.8972$	$c = -0.4393$
	R^2: 0.9995	$g = 0.2925$	$g = 2.286$
	Adjusted R^2: 0.9995	*SSE*: 0.00343	$h = 2.217$
	RMSE: 0.00540	R^2: 0.9999	$k = 0.2926$
		Adjusted R^2: 0.9999	*SSE*: 0.00346
		RMSE: 0.001956	R^2: 0.9999
			Adjusted R^2: 0.9999
			RMSE: 0.00197
Longal	$k = 0.3462$	$a = 0.8619$	$a = 0.2803$
	$n = 0.8452$	$k = 0.237$	$b = 0.5799$
	SSE:0.03826	$b = 0.1446$	$c = 0.1469$
	R^2: 0.9992	$g = 2.218$	$g = 0.2363$
	Adjusted R^2: 0.9992	*SSE*: 0.00164	$h = 2.189$
	RMSE: 0.00652	R^2: 1.000	$k = 0.2363$
		Adjusted R^2: 1.000	*SSE*: 0.00104
		RMSE: 0.00135	R^2: 1.000
			Adjusted R^2: 1.000
			RMSE: 0.00108

RMSE, calculated by Equation (6); SSE, calculated by Equation (2).

$$R^2adj = 1 - \frac{SSE \times (n-1)}{SST \times \upsilon} \quad where\ \upsilon = n - m \qquad (5)$$

$$RMSE = \sqrt{\frac{SSE}{\upsilon}} \qquad (6)$$

where $y_{exp,i}$ and $y_{model,i}$ are the experimental and predicted values for the i observation, respectively, n is the number of observations and m is the number of parameters in each model (Yaldýz and Ertekýn 2001; Togrul and Pehlivan 2003).

Physicochemical Characterization

Color. The color of chestnut slices was determined during the drying experiments by a Minolta CR-400 colorimeter in CIELab color space, through the coordinates: L^*, a^* and b^*, using the Spectra Magic Nx software (version CM-S100W 2.03.0006, Konica Minolta Company, Osaka, Japan) described in a previous study (Delgado *et al.* 2014). The C^* (chroma or saturation) and h^* (hue angle) were also calculated by the following equations:

$$C^* = \sqrt{a^{*2} + b^{*2}} \qquad (7)$$

$$h^* = \arctan\left(\frac{b^*}{a^*}\right) \qquad (8)$$

chroma (C^*) measures the purity or saturation of the color, while hue (h^*) denotes the subtle distinction or variation in color (Rajasekar *et al.* 2012). In order to analyze the changes on color along the drying process, this parameter was determined at the beginning (color of fresh chestnut, considered as reference) and after the drying process on 60 slices. So, the ΔL^*, Δa^*, Δb^*, ΔC^* and Δh^* were determined by the difference of the values at the end and the beginning of the drying process. Moreover, the total color difference (ΔE^*) was also calculated according to

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (9)$$

Proximate Composition

The samples were analyzed for proximate composition (moisture, proteins, fat and ash) using Association of Official Analytical Chemists (AOAC) procedures (AOAC 1995). All reagents were of analytical grade and purchased from Sigma-Aldrich Chemical Co. (St Louis, MO). Crude protein content of the samples was estimated by the macroKjeldahl method (VELP SCIENTIFICA, Usmate Velate, Italy), using a conversion factor of 5.3 (Borges *et al.* 2008; Mendes de Vasconcelos *et al.* 2009); crude fat was determined by extracting 5 g of sample with petroleum ether for 24 h, using a Soxhlet apparatus (P Selecta, Abrera, Barcelona, Spain) and ash content was determined by incineration at 550C (Lenton Thermal Designs Ltd, Hope Valley, UK) for 4 h. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by the method described by Goering and Van Soest (1970). Total carbohydrates were calculated by difference as described by FAO (2003). Total energy was calculated according to Atwater system. All determinations were made in duplicate, comprising six values for each drying treatment performed in triplicate.

Statistical Methods

The statistical analysis was performed on SPSS software (Version No. 20.0). Comparisons were carried out at 95% confidence by application of analysis of variance and when significant differences between samples were observed, the Tukey's Honestly Significant Difference test (Tukey's HSD post hoc) was applied.

RESULTS AND DISCUSSION

Drying Kinetics

The drying curves of the two chestnut varieties, previously cut in slices, are shown in Fig. 3. These curves are typical drying curves with two phases. At the beginning the drying rate decreased rapidly, followed by a slowly decrease. Both varieties showed similar behaviors along the drying time. Small differences were detected on the initial phase, probably due to their different initial moisture contents, having Judia higher moisture content (52.7%) than Longal variety (48.5%) (Fig. 3A). However, by analyzing Fig. 3B we can see that to reach the same moisture ratio (e.g., 0.20), the Judia variety lost water more easily than Longal, since a shorter period of time was needed (around 5 h) for the former, while Longal needed a little longer than 6 h to achieve the same value.

Three different mathematical models, namely Page (with one exponential), two-term (with two exponentials) and modified Henderson and Pabis (with three exponentials) models were tested to describe the behavior of chestnuts along drying. The model parameters and the statistics used to evaluate the models suitability are presented in Table 1. It was found that all models described well the experimental data. From the statistical parameters calculated, it was observed that the quality of the fit was good for both chestnut varieties subjected to drying (Table 1), with R^2 and adjusted R^2 in the range of 0.9992 to 1. As all values were near 1, these models described very well the experimental data. *SSE* and *RMSE* also presented low values (close to zero, as desired), varying between 0.00104 to 0.0383 and 0.00108 to 0.00652, respectively. In general terms, after observing the statistical parameters of the three models, a

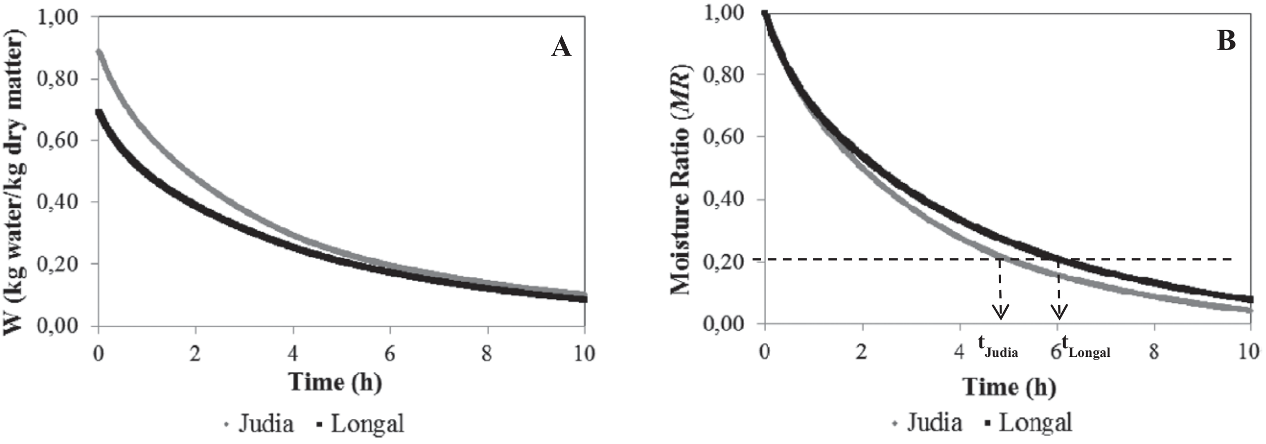

FIG. 3. DRYING RATES IN TERMS OF MOISTURE CONTENT (A) AND MOISTURE RATIO (B) ALONG DRYING TIME FOR LONGAL AND JUDIA VARIETIES

slight improvement was obtained when using two exponential terms compared with Page model with a single exponential. However, with this simple model, good results were obtained. So, this model may be used in the future to predict very satisfactorily the drying curves of chestnut slices.

Effect of Hot-Air Convective Drying on Sliced Chestnut Color

Color is a highly appreciated property by chestnut consumers. Thus, it is important to analyze the effect of drying in this physical characteristic. The results concerning the color changes throughout drying time are detailed in Table 2. Significant interactions between variety and drying time were always observed ($P < 0.001$).

An increase in ΔL^* absolute values was observed along drying until 4 h for Longal and 6 h for Judia varieties. After this period, the values remained almost constant. Moreira *et al.* (2005) observed a decrease on this parameter when analyzing the L^* values of peeled and cut chestnuts after drying at 45, 55 and 65C in line with that observed in the present work. In our study, a decrease in the L^* values was

TABLE 2. COLOR PARAMETERS ALONG AIR CONVECTION DRYING AT 50C FOR TWO CHESTNUT VARIETIES, LONGAL AND JUDIA

	Air convection drying						*P*
Parameter	t = 1 h	t = 2 h	t = 4 h	t = 6 h	t = 8 h	t = 10 h	Variety × Time
ΔL^*							
Longal	$-1.64 \pm 3.34^{c,A}$	$-3.11 \pm 4.69^{b,A}$	$-5.22 \pm 5.70^{a,A}$	$-4.70 \pm 4.84^{a,A}$	$-5.21 \pm 3.97^{a,A}$	$-4.16 \pm 4.27^{a,b,A}$	<0.001
Judia	$-1.59 \pm 3.29^{c,A}$	$-2.44 \pm 3.21^{c,A}$	$-3.76 \pm 3.92^{b,B}$	$-5.32 \pm 4.04^{a,A}$	$-4.84 \pm 5.01^{a,b,A}$	$-5.81 \pm 4.13^{a,B}$	
Δa^*							
Longal	$0.56 \pm 0.74^{a,A}$	$0.72 \pm 0.91^{a,b,A}$	$0.92 \pm 1.53^{b,c,A}$	$1.39 \pm 1.00^{d,A}$	$1.13 \pm 1.09^{c,d,A}$	$1.19 \pm 0.85^{c,d,A}$	<0.001
Judia	$0.53 \pm 0.90^{a,A}$	$0.64 \pm 0.92^{a,b,A}$	$0.88 \pm 0.97^{b,c,A}$	$0.86 \pm 1.08^{b,c,B}$	$1.16 \pm 0.95^{c,d,A}$	$1.34 \pm 0.78^{d,A}$	
Δb^*							
Longal	$-0.54 \pm 4.28^{a,b,A}$	$0.46 \pm 4.33^{b,A}$	$0.30 \pm 5.65^{b,A}$	$-1.54 \pm 4.62^{a,A}$	$-0.08 \pm 4.16^{a,b,A}$	$-1.44 \pm 4.55^{a,A}$	<0.001
Judia	$0.39 \pm 4.38^{b,c,A}$	$-0.04 \pm 5.01^{b,c,A}$	$-0.64 \pm 4.54^{a,b,c,A}$	$0.75 \pm 5.29^{c,B}$	$-1.00 \pm 5.13^{a,b,A}$	$-1.56 \pm 4.17^{a,A}$	
ΔC^*							
Longal	$-0.59 \pm 4.30^{a,b,c,A}$	$0.40 \pm 4.34^{c,A}$	$0.25 \pm 5.65^{c,A}$	$-1.66 \pm 4.62^{a,A}$	$-0.17 \pm 4.19^{b,c,A}$	$-1.54 \pm 4.58^{a,b,A}$	<0.001
Judia	$0.34 \pm 4.41^{b,c,A}$	$-0.10 \pm 5.03^{b,c,A}$	$-0.72 \pm 4.57^{a,b,c,A}$	$0.68 \pm 5.31^{c,B}$	$-1.09 \pm 5.14^{a,b,A}$	$-1.66 \pm 4.18^{a,A}$	
Δh^*							
Longal	$-1.31 \pm 1.56^{c,A}$	$-1.88 \pm 2.08^{b,c,A}$	$-2.39 \pm 4.05^{a,b,A}$	$-3.20 \pm 2.36^{a,A}$	$-2.91 \pm 2.49^{a,A}$	$-2.67 \pm 1.83^{a,b,A}$	<0.001
Judia	$-1.33 \pm 1.69^{d,A}$	$-1.52 \pm 1.87^{c,d,A}$	$-2.05 \pm 1.84^{b,c,A}$	$-1.98 \pm 2.02^{b,c,B}$	$-2.47 \pm 2.06^{a,b,A}$	$-3.01 \pm 1.91^{a,A}$	
ΔE^*							
Longal	$5.02 \pm 2.82^{a,A}$	$5.93 \pm 4.09^{a,b,A}$	$8.10 \pm 5.41^{d,A}$	$7.58 \pm 3.82^{c,d,A}$	$6.80 \pm 4.05^{b,c,A}$	$6.99 \pm 3.37^{b,c,d,A}$	<0.001
Judia	$4.83 \pm 3.20^{a,A}$	$5.69 \pm 3.18^{a,b,A}$	$6.42 \pm 3.29^{b,B}$	$7.84 \pm 3.72^{c,A}$	$7.97 \pm 3.78^{c,B}$	$7.83 \pm 3.41^{c,B}$	

Mean ± standard devaition with different small letter (a–d) superscripts on the same row are significantly different ($P < 0.05$). Mean ± standard deviation with different capital letter (A–B) superscripts on the same column are significantly different ($P < 0.05$).

also detected, explaining the negative values obtained for the ΔL^* (Table 2). Moreover, in the present work, differences between varieties were observed at the beginning (0 h) (87.3 for Longal and 86.5 for Judia varieties) and after 6 or more hours of drying. Judia always showed lower L^* values than Longal (data not shown), indicative of lower lightness.

There was also a significant increase in Δa^* values (which indicates higher red proportions) along drying for both varieties. For Longal variety, the Δa^* values remained constant after 6 h, while for Judia the Δa^* values kept on constant after 8 h. Moreira *et al.* (2005) also observed an increase in a^* values of both peeled and cut chestnuts after drying at 45, 55 and 65C.

Regarding Δb^* and ΔC^* parameters, slight variations were observed along drying for both varieties. For Longal variety, after 10 h of drying, the yellowness variation (Δb^* value) and chroma variation (ΔC^*) were not significantly different to 1 h of drying. On contrary, a significant difference was observed for Judia.

Regarding the hue (h^*) values, both varieties presented a yellow predominant color (h^* values around 90°) in line with the higher effect of b^* component than a^*, due to the higher values of the former (data not shown). However, along drying time, the variation increased in absolute terms for both varieties.

Total color differences (ΔE^*) were evaluated along drying and values higher than zero were always observed, suggesting that chestnuts color changed along dehydration; however, this variation did not result in a different color because ΔE^* values were less than 12 (Cecchini *et al.* 2011) (Fig. 1). For Longal variety, the highest variation on ΔE^* values was observed at 4 h of drying, remaining almost constant after that time. For Judia, a more constant increase in this parameter was observed, remaining stable after 6 h. These results may be related to the occurrence of enzymatic browning reactions due to polyphenol oxidase activity during drying, as well as to nonenzymatic browning reactions, namely Maillard and caramelization reactions. In fact, Judia variety presents slight higher values of sugars and proteins than Longal that may favor the occurrence of such reactions, as explained subsequently, and supported by the increased redness (a^*), typical color of these browning products.

Effect of the Hot-Air Convective Drying on Sliced Chestnut Proximate Composition

The results obtained for proximate composition of the two chestnut cultivars along the drying time are shown in Table 3. In almost all situations, significant interactions between variety and drying time were observed ($P < 0.05$), except for crude protein and NDF. However, for these parameters the individual effects of chestnut variety and/or drying time were significant.

Water is the predominant component in fresh chestnuts (0 h), responsible for its high perishability. Significant differences on moisture contents were found between both varieties, with a mean of 48.5 ± 0.4 g/100 g fresh weight for Longal and 52.7 ± 1.4 g/100 g fresh weigh for Judia. These results were in accordance with the Spanish and Portuguese cultivars analyzed by Míguelez *et al.* (2004) (48.37 to 59.35 g/100 g fresh weight), Pereira-Lorenzo *et al.* (2006) (40.3 to 60.1 g/100 g fresh weight), Borges *et al.* (2008) (46.3 to 53.3 g/100 g fresh weight) and Correia *et al.* (2009) (47.9 to 48.2 g/100 g fresh weight). As expected, the moisture contents decreased along drying and stabilized without significant variations after 8 h for Longal and 6 h for Judia. When comparing both varieties, the significant differences observed at the beginning (0 h) disappeared, supported by a higher moisture loss in Judia, confirming the differences on drying kinetics referred previously.

Significant differences were always found in ash content between the two varieties, with an average of 1.76 ± 0.02 g ash/100 g dry weight for Longal and 2.25 ± 0.12 g ash/100 g dry weight for Judia at the beginning of the drying experiments (0 h). The differences between varieties may be related to genetic differences, altitude and soil type, among others, as proposed by Pereira-Lorenzo *et al.* (2006). In fact both varieties were from different locations; however, our values are in agreement with Ertürk *et al.* (2006) (1.02 to 3.22 g ash/100 g dry weight), Pereira-Lorenzo *et al.* (2006) (1.8 to 3.2 g ash/100 g dry weight), Borges *et al.* (2008) (1.60 to 2.20 g ash/100 g dry weight) and Correia *et al.* (2009) (1.9 to 2.1 g ash/100 g dry weight). Small variations were observed in Longal along drying, while no significant variations were observed in Judia variety. This was expected as this property is not predictable to vary along dehydration.

The fat content in chestnuts is low, but still significantly higher in Longal (3.26 ± 0.11 g fat/100 g dry weight) than Judia (2.77 ± 0.45 g fat/100 g dry weight) before drying. These values are similar to previous studies such as Ertürk *et al.* (2006) (0.49 to 2.01 g fat/100 g dry weight), Pereira-Lorenzo *et al.* (2006) (1.7 to 4.0 g fat/100 g dry weight), Borges *et al.* (2008) (1.73 to 3.10 g fat/100 g dry weight) and Correia *et al.* (2009) (2.6 to 3.0 g fat/100 g dry weight) for Turkish, Spanish and Portuguese varieties. Along drying, the two varieties presented a similar fat content. Furthermore, the fat values determined at the beginning and after 10 h of the drying process were not significantly different, indicating that this parameter was almost unaffected by the thermal process.

Crude protein did not show significant differences along drying time but differed between the two chestnut varieties. At the beginning, Longal and Judia varieties presented crude

TABLE 3. MOISTURE CONTENT AND NUTRITIONAL COMPOSITION ALONG AIR CONVECTION DRYING FOR TWO CHESTNUT VARIETIES, LONGAL AND JUDIA

	Air convection drying							*P*
Parameter	t = 0 h	t = 1 h	t = 2 h	t = 4 h	t = 6 h	t = 8 h	t = 10 h	Variety × Time
Moisture (g water/100g chestnut after drying)								
Longal	$48.5 \pm 0.4^{f,A}$	$36.7 \pm 3.1^{e,A}$	$30.8 \pm 2.9^{d,A}$	$17.3 \pm 1.5^{c,A}$	$16.6 \pm 1.9^{b,c,A}$	$11.8 \pm 0.7^{a,b,A}$	$11.0 \pm 0.5^{a,A}$	0.013
Judia	$52.7 \pm 1.4^{e,B}$	$38.9 \pm 3.6^{d,A}$	$32.0 \pm 1.5^{c,A}$	$17.6 \pm 3.0^{b,A}$	$11.5 \pm 0.8^{a,B}$	$11.4 \pm 1.3^{a,A}$	$10.3 \pm 0.2^{a,A}$	
Total ash (g ash/100g dry weight)								
Longal	$1.76 \pm 0.02^{b,c,A}$	$1.78 \pm 0.03^{c,A}$	$1.71 \pm 0.03^{a,b,A}$	$1.68 \pm 0.03^{a,A}$	$1.78 \pm 0.05^{c,A}$	$1.78 \pm 0.02^{c,A}$	$1.76 \pm 0.04^{b,c,A}$	0.012
Judia	$2.25 \pm 0.12^{a,B}$	$2.25 \pm 0.05^{a,B}$	$2.26 \pm 0.08^{a,B}$	$2.35 \pm 0.15^{a,B}$	$2.35 \pm 0.07^{a,B}$	$2.30 \pm 0.06^{a,B}$	$2.24 \pm 0.07^{a,B}$	
Crude fat (g fat/100g dry weight)								
Longal	$3.26 \pm 0.11^{c,A}$	$2.78 \pm 0.40^{a,A}$	$2.81 \pm 0.12^{a,A}$	$3.17 \pm 0.08^{b,c,A}$	$2.66 \pm 0.15^{a,A}$	$2.83 \pm 0.16^{a,b,A}$	$2.98 \pm 0.15^{a,b,c,A}$	0.012
Judia	$2.77 \pm 0.45^{a,B}$	$2.69 \pm 0.41^{a,A}$	$2.77 \pm 0.24^{a,A}$	$2.48 \pm 0.32^{a,B}$	$2.50 \pm 0.11^{a,A}$	$2.71 \pm 0.33^{a,A}$	$3.00 \pm 0.19^{a,A}$	
Crude protein (g protein/100g dry weight)								
Longal	$3.97 \pm 0.20^{a,A}$	$4.81 \pm 0.15^{a,A}$	$4.20 \pm 0.32^{a,A}$	$4.37 \pm 0.12^{a,A}$	$4.42 \pm 0.38^{a,A}$	$4.34 \pm 0.52^{a,A}$	$4.68 \pm 0.28^{a,A}$	0.156
Judia	$5.43 \pm 0.46^{a,B}$	$5.41 \pm 0.42^{a,A}$	$5.44 \pm 0.30^{a,B}$	$5.29 \pm 0.65^{a,B}$	$5.87 \pm 0.30^{a,B}$	$5.59 \pm 0.53^{a,B}$	$5.09 \pm 0.03^{a,A}$	
NDF (g NDF/100g dry weight)								
Longal	$9.74 \pm 1.57^{a,A}$	$16.78 \pm 2.50^{b,c,A}$	$18.08 \pm 3.24^{c,A}$	$17.87 \pm 1.66^{b,c,A}$	$16.73 \pm 2.84^{b,c,A}$	$17.78 \pm 1.99^{b,c,A}$	$13.49 \pm 0.63^{a,b,A}$	0.057
Judia	$5.93 \pm 0.81^{a,B}$	$13.52 \pm 3.63^{b,A}$	$17.35 \pm 2.06^{b,c,A}$	$16.49 \pm 2.51^{b,c,A}$	$15.46 \pm 1.39^{b,c,A}$	$18.00 \pm 1.59^{c,A}$	$15.76 \pm 2.35^{b,c,A}$	
ADF (g ADF/100g dry weight)								
Longal	$3.72 \pm 0.43^{b,A}$	$3.46 \pm 0.37^{a,b,A}$	$3.08 \pm 0.37^{a,b,A}$	$3.26 \pm 0.40^{a,b,A}$	$2.93 \pm 0.32^{a,A}$	$3.19 \pm 0.42^{a,b,A}$	$3.22 \pm 0.34^{a,b,A}$	0.016
Judia	$3.45 \pm 0.30^{a,b,A}$	$3.23 \pm 0.22^{a,A}$	$3.66 \pm 0.46^{a,b,B}$	$3.38 \pm 0.33^{a,b,A}$	$3.22 \pm 0.44^{a,A}$	$4.05 \pm 0.62^{b,B}$	$3.58 \pm 0.52^{a,b,A}$	
Total carbohydrates (g carbohydrates/100g dry weight)								
Longal	$91.0 \pm 0.2^{a,b,c,A}$	$90.7 \pm 0.4^{a,b,A}$	$91.3 \pm 0.3^{c,A}$	$90.8 \pm 0.1^{a,b,c,A}$	$91.1 \pm 0.3^{b,c,A}$	$90.8 \pm 0.3^{a,b,A}$	$90.6 \pm 0.3^{a,A}$	<0.001
Judia	$89.6 \pm 0.4^{a,B}$	$89.6 \pm 0.4^{a,b,B}$	$89.5 \pm 0.2^{a,B}$	$90.2 \pm 0.4^{b,B}$	$89.3 \pm 0.3^{a,B}$	$89.4 \pm 0.2^{a,B}$	$89.7 \pm 0.2^{a,b,B}$	
Energetic value (kcal/100g dry weight)								
Longal	$412 \pm 0.5^{c,A}$	$410 \pm 2^{a,b,A}$	$410 \pm 0.6^{a,b,A}$	$412 \pm 0.4^{c,A}$	$409 \pm 0.6^{a,A}$	$410 \pm 0.5^{a,b,A}$	$411 \pm 1^{b,c,A}$	0.003
Judia	$409 \pm 2^{a,B}$	$408 \pm 2^{a,A}$	$409 \pm 1^{a,B}$	$407 \pm 2^{a,B}$	$408 \pm 1^{a,B}$	$408 \pm 1^{a,B}$	$409 \pm 1^{a,B}$	

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

ADF, acid detergent fiber; NDF, neutral detergent fiber.

protein contents of 3.97 ± 0.20 and 5.43 ± 0.46 g protein/100 g dry weight, respectively. The higher protein content in Judia than Longal might support the higher formation of Maillard products during chestnut drying, as previously suggested. Our values are in agreement with those published by Míguelez *et al.* (2004) (6.02 to 8.58 g protein/100 g dry weight), Ertürk *et al.* (2006) (4.88 to 10.87 g protein/100 g dry weight), Pereira-Lorenzo *et al.* (2006) (4.5 to 9.6 g protein/100 g dry weight), Borges *et al.* (2008) (4.87 to 7.37 g protein/100 g dry matter) and Correia *et al.* (2009) (4.3 to 5.0 g protein/100 g dry weight). Míguelez *et al.* (2004) refer that differences between varieties may be related to differences in soil type, as soils with a greater amount of schist present higher protein content than granite-based soils.

ADF and NDF showed small variations along drying; however, generally, no significant differences were observed between 0 and 10 h. Judia showed a lower initial content in NDF than Longal variety. Nevertheless, no significant differences between varieties were observed along drying. Also for ADF, similar results were obtained for both varieties for almost all drying times. Our ADF (3.45 and 3.72 g ADF/100 g dry weight) and NDF (5.93 and 9.74 g NDF/100 g dry weight) values were similar to those obtained by Pereira-Lorenzo *et al.* (2006) (2.3 to 4.5 g ADF/100 g dry weight and 9.4 to 28.5 g NDF/100 g dry weight) and Borges *et al.* (2008) (1.89 to 3.15 g ADF/100 g dry weight and 13.8 to 24.4 g NDF/100 g dry weight).

The level of carbohydrates in chestnuts was high (91.0 ± 0.2 g carbohydrates/100 g dry weight for Longal and 89.6 ± 0.4 g carbohydrates/100 g dry weight for Judia variety). Our results are a little higher than those published by Ertürk *et al.* (2006), 75.32 to 86.31 g carbohydrates/100 g dry weight, for several Turkish chestnut cultivars. Nevertheless, after expressing the results in fresh weight, our results (46.9 g carbohydrates/100 g fresh weight for Longal and 42.4 g carbohydrates/100 g fresh weight for Judia variety) were similar to Barreira *et al.* (2009) for both varieties (44.1 g carbohydrates/100 g fresh weight for Longal and 42.1 g carbohydrates/100 g fresh weight for Judia variety). Concerning drying, no significant differences were observed between 0 and 10 h for each variety. So, carbohydrates degradation was not significant during the drying process, the remaining sugar contents were almost unchanged. However, significant differences between varieties were always found, having Longal variety slight higher values than Judia.

Concerning energetic value, Judia always presented lower values than Longal but the differences were almost negligible. At the beginning (0 h), Longal had 212 kcal/100 g while Judia had 193 kcal/100 g, similar to those obtained by Barreira *et al.* (2009) for the same varieties (193 kcal/100 g for Longal and 187 kcal/100 g fresh weight for Judia). Regarding drying, no significant differences were detected in Judia along time. Even though small variations were observed for Longal along drying, the energetic values on a dry basis at 10 h were identical to that presented at 0 h, indicating only slight changes in the macronutrients along the drying process.

When comparing the energetic value of dried chestnut slices per 100 g of product (367 kcal/100 g for both varieties) with other kind of snacks, such as fried peanuts and flavored chips, the former had approximately 32 to 40% less calories than the other snacks, suggesting it to be a healthy and less caloric substitute. On the other hand, the dried chestnut slices had a similar energetic value to dried apple (346 kcal/100 g). This product was developed by a Portuguese enterprise and it had earned a nutrition award at 2013, being labeled as a healthy snack. The demand of this kind of product has nowadays been increasing due to greater consumer concern with health. Furthermore, we performed a preliminary sensory study where 10-member semi-trained panelists were asked to rate the overall acceptance of the dried sliced chestnuts in a 10-cm nonstructured scale (0 means unacceptable and 10 means very acceptable). Good results were obtained with an average ± standard deviation equal to 7.36 ± 1.41.

CONCLUSIONS

Even though slight differences in moisture content were found at the beginning between Longal and Judia varieties, among other properties, the drying behaviors were similar and the experimental data were well adjusted by Page, two-term and modified Henderson and Pabis models. This is important from the industrial point of view as not adjustments in the drying process are expected to be necessary for these two varieties, being their drying behaviors also easily predicted. Although color differences were detected after drying at 50C for 10 h, changes on chestnut macronutrients were generally not observed. The variability between varieties was higher than that observed along drying for each variety. Due to their low caloric and gluten-free contents, dried chestnut slices appear as an excellent substitute to other types of snacks.

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