Bioactive compounds and physicochemical characterization of dried apricot (*Prunus armeniaca* L.) as affected by different drying temperatures

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**ABSTRACT**

The influence of diverse hot-air drying temperature on bioactive compounds, nutritional components, and physical aspects of apricot (*Prunus armeniaca* L. var. Tilton) fruits from 40°C to 80°C was evaluated. Firstly, drying kinetics was modeled by a Diffusion model and Weibull equation, this last provided a good fit to the experimental data. The effect of drying conditions on the color and microstructure showed noticeable modifications due to an increase of air-drying temperature. Besides, a reduction of antioxidant activity, total phenolic and flavonoid contents with an increase of drying temperature were observed. As to vitamin C and β-carotene, they were much more affected by the long drying times (>1000 min) than high temperatures (>60°C). Sucrose, fructose, and glucose were identified in all apricot samples, being sucrose the predominant sugar. Thus, results from the present study indicate that the hot-air drying technology continues to be applicable for obtaining a dried functional product of good quality.

**RESUMEN**

La influencia de diversas temperaturas de secado se evaluó desde 40 a 80°C sobre los compuestos bioactivos, componentes nutricionales y aspectos físicos del albaricoque (*Prunus armeniaca* L. var. Tilton) fueron evaluadas. En primer lugar, la cinética de secado se modelo por el modelo de Difusión y la ecuación de Weibull, esta última entregó una buena calidad de ajuste sobre los datos experimentales. El efecto de las condiciones de secado sobre el color y microestructura mostró modificaciones considerables al momento de elevar la temperatura de secado. Además, se observó una reducción de la actividad antioxidante, fenoles totales y contenidos de flavonoides con un aumento de la temperatura de secado. En cuanto a vitamina C y β-caroteno, estos comuestos fueron mucho más afectados por el prolongado tiempo de secado (>1000 min) que por las altas temperaturas (>60°C). Sacarosa, fructosa y glucosa se identificaron en todas las muestras de albaricoque, siendo sacarosa el azúcar predominante. Por lo tanto, los resultados del presente estudio indican que la tecnología de secado por aire caliente sigue siendo aplicable para obtener un producto funcional deshidratado.

1. Introduction

*Prunus armeniaca* L. belongs to the *Rosaceae* family and *Prunusidea* subfamily, commonly known as apricot. It is a plant with edible delicious fruits cultivated in all Mediterranean countries, in South Africa as well as in South and North America (Ali, Masud, & Abbasi, 2011; Erdogan-Orhan & Kartal, 2011; Huang et al., 2013). The apricot fruit is highly appreciated by consumers due to its delicate taste, appealing smell, vivid colors, and numerous nutritional properties which is a result of its rich content of minerals, fibers, sugars and bioactive phytochemicals, including vitamin C, β-carotene, thiamine, riboflavin, niacin, and pantothenic acid, as well as phenols, carotenoids, and tocopherols (Karabulut, Topcu, Duran, Turan, & Ozturk, 2007).

Biologically active components, like polyphenols and carotenoids, have in the last decades attracted much interest due to their antioxidant properties and their ability to protect against chronic diseases (Akin, Karabulut and Topcu, 2008; Ali et al., 2011; Erdogan-Orhan & Kartal, 2011; Huang et al., 2013; Madrau et al., 2009). When being used as dietary antioxidants they provide effective protection from oxidative damage in living organisms, which provides the apricot fruits some pharmacological significance besides its highly nutritional properties (Dragovic-Uzelac, Levaj, Mrkic, Bursac, & Boras, 2007; Igual, Garcia-Martinez, Martin-Esparza, & Martinez-Navarrete, 2012).

Apricot is a climacteric fruit and in the fresh state, it cannot be stored for a long time, partly due to a high respiration rate and a rapid ripening process. The shelf life of apricot is usually prolonged through different preservation methods such as canning, freezing, drying or packing in a controlled atmosphere. Drying reduces the moisture content of apricots to a safe level and allows storage over an extended period (Doymaz, 2004; Huang et al., 2013; Igual et al., 2012). However, a high thermal load during drying may cause a decrease of phenols or...
degradation of carotenoids because of a long exposure to oxygen (Madrau et al., 2009). Besides, the effect of the drying conditions on the microstructure of fruits has been found to occur at the microstructural level that may consequently affect food macrostructure (Ramírez, Troncoso, Muñoz, & Aguilara, 2011). Although the effect of the drying process on bioactive compounds and antioxidant capacity of apricot fruits is not fully understood (Madrau et al., 2009), there is always the chance this preservation method could be improved to minimize the product damage (Di Scala Vega-Gálvez, Uribe, Oyanadel, Miranda, & Vergara, 2011).

In literature, there are diverse research works regarding apricots drying and drying temperature effect on mass diffusivity and some bioactive compounds. However, these research have been restricted in temperature range and subsequently determination of antioxidant capacity (Madrau et al., 2009), mass diffusion coefficient (Cărleșcu, Arsenoaia, Roșca, & Țenu, 2017), and drying kinetic modeling (Faal, Tavakoli, & Ghobadian, 2015). In addition, others studies were evaluated taking account of pomace (Zhang, Song, Wang, Zhao, & Fan, 2016) and kernels (Kayran & Doymaz, 2017) of apricot during the drying process.

In consequence of the above mentioned, it is necessary a full assessment of the air-hot drying process of apricots fruits under a wide range of temperature and its associated effect on the different bioactive compounds as well as by other physical quality features. Therefore, this work is aiming to evaluate the effect of different hot-air drying temperatures (40–80°C) on drying kinetics, antioxidant activity, polyphenolic compounds, color, and microstructure of apricot (Prunus armeniaca L.) fruits.

2. Materials and methods

2.1. Raw material

Apricot (var. Tilton) fruits were harvested during the first week of December 2017 (early harvest) from the Chilipín town (31°52′59″ S; 70°43′50″ W), Province of Salamanca, Region of Coquimbo, Chile. The samples were selected to provide a homogeneous group, based on their color, size, freshness, and have no signs of mechanical damage according to visual analysis, and they were refrigerated at 5.0 ± 0.2°C until drying process (INIA, 2002). Moisture content was determined by AOAC method 934.06 (AOAC, 1990) in a vacuum oven (Gallenkamp, OVL570, Leicester, UK). The water activity (aw) was determined at 25°C by a water activity meter (Aqua Lab, 4 TE, Pullman, USA). Acidity (% malic acid) was determined by the adapted AOAC method 942.15A (AOAC, 1990), pH was measured with a potentiometer (Extech Instruments, Microcomputer pH-Vision 246072, USA), and total soluble sugar content was calculated with an Abbé refractometer (ATAGO, 1-T, Japan). All the analyses were triplicated and expressed in g 100 g⁻¹ fruit. Also, the mean equatorial diameter of berries as measured by a Vernier caliper (Mitutoyo Digimatic Caliper, 500–144, People’s Republic of China).

2.2. Drying experiments and modeling

Drying experiments were carried out in triplicate at five temperatures (40°C, 50°C, 60°C, 70°C, and 80°C) at a constant air-flow of 1.5 ± 0.2 m s⁻¹ in a perpendicular direction to the layer of samples. The selection of drying temperatures was based on both industrial and handicraft drying of apricots fruits in the Coquimbo Region, in addition, the range of temperature was extended for achieving greater information of dried apricots quality parameters. The apricot samples were arranged in a thin layer in a stainless steel basket with a load density of 14.51 ± 0.66 kg m⁻². The drying process was carried out in a convective dryer designed and built at the Department of Food Engineering of Universidad de La Serena.

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Modeling of drying kinetics was performed by means of two equations widely used in most food and biological materials, namely Diffusion equation based on Fick’s second law (Eq. 1) and Weibull model (Eq. 2). Water diffusion values (Dwe) were determined based on one-dimensional transport in a sphere of radius r. Both models used the relationship established on MR, which relates the gradient of sample moisture content in real time with the initial moisture content and the equilibrium moisture content, MR = (Xwe-Xw0)-(Xwe-Xwe. In this research, the shrinkage phenomenon was assumed as negligible, although is widely well known that it is notorious in fruit dehydration (Lemus-Mondaca, Moraga, Vega-Gálvez, & Zambra, 2013).

\[
MR = \frac{6 \pi^2}{r^2} \exp \left( -\frac{D_{we} r^2 t}{r^2} \right) \tag{1}
\]

\[
MR = \exp \left[ -\frac{t}{\beta} \right]^\alpha \tag{2}
\]

where Xw0, Xwe, and Xwe are the initial one, at a time t, and at equilibrium moisture content (g water g⁻¹ dry matter, dm) respectively, Dwe is the water diffusivity (m² s⁻¹), r is the mean radius of the sphere (m), β is the scale parameter of the Weibull model, α is the shape parameter (dimensionless), and t is the drying time.

2.3. Microstructure analysis

A cryostage CT 1500 C (Oxford Instruments, Witney, UK) linked to an electron microscope JEOL-JSM-5410 (JEOL, Tokyo, Japan) was used to observe fresh and dried apricot microstructure. As to dried apricots, these were rehydrated for 10 h at room temperature. Rehydrated samples were cryo-fixed by immersion in slush nitrogen (−210°C), and then quickly transferred to the cryostage at 1 kPa to be fractured. The sublimation was carried out at −90°C, 1.33–0.67 kPa for 15 min, and the final point was determined by direct microscopic observation (5 kV). Once again, in the cryostage unit, the sample was gold-coated using an ionization current of 2 mA and applying vacuum (0.2 kPa) for 3 min and viewed on the Scanning Electron Microscopy (SEM) cold-stage. The fractured surface was viewed directly while it was maintained at −150°C, approximately. Observations were carried out when the microscope was at 10 kV and the working distance was set at 15 mm. The micrographs were taken at 500× magnification to observe changes in cell structure. Two samples were studied for each treatment.

2.4. Surface color

The color of apricot was measured with a Hunter Lab colorimeter (MinScan XE Plus, Reston, Virginia, USA) and expressed by CIELab coordinates, L* (brightness), a* (redness/greenness), and b* (yellowness/blueness), in addition to standard illuminant D65 and 10° observer angle (López et al., 2010). Measurements were performed in five replicates and the results were averaged. The total color difference (ΔE) was calculated by Eq. (3) where L₀, a₀, and b₀ are the control values for fresh fruit.
\[ \Delta E = \left[ (a^* - a_o)^2 + (b^* - b_o)^2 + (L^* - L_o)^2 \right]^{0.5} \] 

### 2.5. Extraction of phenolic compounds

The first extraction was carried out with 30 mL of methanol 50% v/v and then a second with 30 mL of acetone 70% v/v agitated at 250 rpm x 60 min on an orbital shaker (Boeco, OS20, Hamburg, Germany), according to Vasco, Ruales, and Kamal-Eldin (2008). After centrifugation (Eppendorf, 5804 R, Hamburg, Germany) at 5000 rpm x 3 min, the supernatant was removed and extraction was repeated once again with the same residue as mentioned above for 30 min. The combined extracts were evaporated under vacuum (Multivapor Büchi P-6, Flawil, Switzerland) at 37°C and redissolved in 10 mL methanol-formic acid (99:1). The extract was stored at 4°C until further analysis.

### 2.6. Total phenolic (TPC) and flavonoid content (TFC)

TPC was determined colorimetrically using Folin-Ciocalteu (FC) reagent according to Chua et al. (2008) with some modifications. A 0.5 mL aliquot of a fruit extract was transferred to a glass tube and mixed with 0.5 mL of FC reagent; after 5 min, a 2 mL Na\(_2\)CO\(_3\) solution (200 mg mL\(^{-1}\)) was added and vortexed for about 20 s. The reaction proceeded protected from daylight for 15 min at ambient temperature. Ten milliliters of ultra-pure water was added and the precipitate formed was removed by centrifugation (5804 R, Hamburg, Germany) at 4000 rpm x 5 min. The absorbance was read at 725 nm using a spectrophotometer (Spectronic\(^{®}\), 20 Genesys, Illinois, USA) and compared to a gallic acid calibration curve. Results were expressed as mg gallic acid equivalent (GAE) 100 g\(^{-1}\) dm. As to TFC, this was determined by a colorimetric assay described by Dini, Tenore, and Dini (2010). Briefly, 0.5 mL aliquot of each extract was added into a set of tubes containing 2 mL double distilled water (ddH\(_2\)O). At time zero, 0.15 mL Na\(_2\)NO\(_3\) aqueous solution (5 g 100 mL\(^{-1}\) was added after 5 min, a 0.15 mL Al\(_2\)Cl\(_3\) aqueous solution (10 g 100 mL\(^{-1}\) and at 6 min, 1 mL of 1 M NaOH and finally 1.2 mL of ultra-pure water were added and shaken thoroughly. Absorbance was read at 415 nm by using a spectrophotometer. TFC was expressed as mg catechin equivalent (CE) 100 g\(^{-1}\) dm.

### 2.7. Determination of DPPH radical scavenging capacity

The 2,2-Diphenyl-1-picryl-hydrazyl (DPPH) assay was performed by preparing a solution of 50 \(\mu\)M DPPH in methanol and stirred for 40 min and 0.1 mL of apricot extract was then mixed with 3.9 mL of the DPPH solution and incubated for 30 min in the dark. Absorbance was read at 517 nm. The total antioxidant capacity determined by the DPPH assay was expressed as \(\mu\)mol Trolox equivalent (TE) 100 g\(^{-1}\) dm.

### 2.8. Identification of phenolic compounds

An HPLC system (Santa Clara, Agilent 1200 series, CA, USA), equipped with a high-pressure pump (model G1311A), an automatic injector (model G1329B), a column oven (model G1316A) and a diode array detector (DAD, model G1315D) controlled by ChemStation software was used. The analytical column was a Kromasil 100-5C18 (250 x 4.6 mm) (Eka Chemical, Sweden). The flow rate was 0.7 mL min\(^{-1}\), and the eluates were monitored at 280, 310 and 370 nm at 25°C. The mobile phase was solvent A (formic acid 0.1%, pH 3) and B (100% Acetonitrile). The elution was initially set at 87% A and 13% B and the gradient elution was as follows: 0–18 min, 13–55% B; 18–23 min, 55–60%; 23–25 min, 60–13% and back to initial conditions within 2 min. Identification of selected phenolic compounds (chlorogenic, syringic and gallic acid, quercetin 3-rutinoside, catechin, epicatechin, and quercetin) in methanol-formic acid (99:1) was obtained by comparison of retention times, spectra and peak area at a maximum absorption wavelength to standards. The results of the main phenolic compounds were expressed in mg 100 g\(^{-1}\) dm.

### 2.9. Determination of vitamin C and \(\beta\)-carotene

The vitamin C extraction method was performed by using 15 mL 5% metaphosphoric acid (MPA) added to a 5.0 g sample and then mixed for 20 min, afterwards the sample was centrifuged under 5000 rpm x 15 min at 10°C. The supernatant was injected for chromatographic analysis (Agilent 1200 series HPLC system) performed by using a Zorbax Eclipse XDB-C18, 4.6 x 150 mm, 5 \(\mu\)m reversed-phase column, a mobile phase containing 5 mM cetyltrimethylammonium bromide as the ion-pairing agent and 50 mM potassium dihydrogenphosphate as the buffer (pH 3.9). The flow rate was of 0.7 mL min\(^{-1}\) for isocratic elution at 20°C and detection at 254 nm. Total vitamin C content was estimated after reduction of dehydroascorbic acid (DHA) with TCEP (tris (2-carboxy ethyl) phosphine hydrochloride) for 30 min (Chebrolu, Jayaprakasha, Yoo, Jifon, & Patil, 2012). Results were expressed as mg vitamin C 100 g\(^{-1}\) dm.

The \(\beta\)-carotene extraction was performed using a solvent mixture of hexane, aceton, and ethanol (50/25/25 v/v/v). Between 1 and 1.5 g of dried samples were accurately weighed and extracted in 25 mL of the solvent mixture using an orbital shaker at 200 rpm for 30 min. The supernatant was separated and the residue re-extracted until colorless. The filtrates were combined and placed in a round-bottomed flask and evaporated to dryness. The dried extract was dissolved in ethyl acetate and then filtered through 0.45 \(\mu\)m membrane filters before being injected to HPLC. The same Agilent 1200 series HPLC system was used, and the column used was a Kromasil 100-SC18, 250 x 4.6 mm, connected to a Kromasil guard column and maintained at 30°C. The flow rate was 1 mL min\(^{-1}\), and the mobile phases were (A) acetonitrile: H\(_2\)O (90:10, v/v/v) adjusted at pH 8.5 and (B) ethyl acetate. The gradient elution program was as follows: 0–5 min, 100–75% A; 5–10 min, 75–30% A; 10–14 min, 30–0% A; 14–15 min, 0–100% A; 15–20 min, 100% A. Absorbance was read at 450 nm and \(\beta\)-carotene was identified based on retention time and peak areas compared to the standard. Results were expressed as mg \(\beta\)-carotene 100 g\(^{-1}\) dm.

### 2.10. Sugar content

The individual content of sugars (glucose, fructose, sucrose, and sorbitol) was determined. The fruits were ground and homogenized with a mill (IKA\(^{®}\) A-11 basic, Wilmington, USA). One gram of mashed fruit was dissolved in 15 mL of methanol (80%) and agitated on a shaker at 200 rpm for 30 min, according to the procedure described by Mrad, Bonazzi, Boudrhioua, Kechau, and Courtois (2012a) with some modifications. The extracted sample was centrifuged for 3 min and supernatant was filtered through 0.45 \(\mu\)m membrane filter and 10 \(\mu\)L were
injected for HPLC Perkin Elmer Flexar LC model (Shelton, Washington, USA) with a refractive index (RI) detector, including a Flexar binary LC Pump, a Flexar LC autosampler and a Flexar column oven. Separation of sugars was carried out using a Supelcosil® LC-NH2, 5μm (25 cmx4.6 mm) with column temperature maintained at 30°C; the mobile phase was acetonitrile:water (82.5:17.5 at pH 5.3) and the flow rate was at 1 mL min⁻¹ for isocratic elution. Sugars in fruit extracts were identified by their retention time compared to the standard. Data were processed by using Total Chrom Software. Sugar contents were expressed as g 100 g⁻¹ dm.

2.11. Statistical analysis

All measurements were performed in triplicate. The precision of the fit between the experimental data and the predicted values for the drying kinetics was evaluated using the coefficient of determination (r²) and chi-square parameter (χ²), described in Eq. (4). The best fit of experimental data to the model is obtained when the r² value is the nearest to 1, and the χ² value is the nearest to zero (Doymaz, 2004).

\[
\chi^2 = \frac{\sum_{i=1}^{N} (M_{exp} - M_{pred})^2}{N - z}
\]

The effect of drying temperatures of different parameters was estimated using Statgraphics Centurion XV (Statistical Graphics Corp., Herndon, Virginia, USA). One-way analysis of variance (ANOVA) with six levels was used to indicate significant differences among samples. Significance testing was performed by using the Fisher’s least significant difference (LSD) test; differences were determined to be statistically significant when p < 0.05. The Multiple Range Test (MRT) included in the statistical program was used to test the existence of homogeneous groups within each of the parameters analyzed.

3. Results and discussion

3.1. Drying process

The mean moisture content (Xw) determined in the fresh apricot was 0.847 ± 0.057 g g⁻¹ fresh weight or 5.54 ± 0.6 g g⁻¹ dm. As expected, a high water activity (aw) of 0.968 ± 0.003 was also determined. Drying at 40°C brought about aw to 0.265 ± 0.041 g g⁻¹ dm and 0.693 ± 0.001, respectively. Similar values were obtained after the drying process at 50°C, 60°C, and 70°C, with Xw and aw of 0.217 ± 0.021 g g⁻¹ dm and 0.649 ± 0.001 at 50°C, 0.183 ± 0.083 g g⁻¹ dm and 0.608 ± 0.002 at 60°C and 0.219 ± 0.014 g g⁻¹ dm and 0.663 ± 0.002 at 70°C. Karabulut et al. (2007) reported that the moisture content of dried apricots was 0.33 g g⁻¹ (dm) when applied in commercial applications. It can be seen that water activity was above the threshold value of 0.60 for mold growth, indicating some kind of vulnerability of apricots dried under such temperature conditions. Only the apricot samples dried at 80°C achieved a low moisture content of 0.160 ± 0.020 g g⁻¹ dm and a safe water activity value of 0.482 ± 0.097. According to Igual et al. (2012) and García-Martínez, Igual, Martín-Esparza, and Martínez-Navarrete (2013) who worked with apricot, the high sugar content (Xs>0.67) may counteract the effect of a high water activity, making microbial contamination less probable. The acidity, pH and total soluble sugar values ranged from 1.22% to 1.97% malic acid, 3.0–3.1, 10.80–13.12%, respectively. Mean equatorial diameter of apricots was 57.3 ± 1.67 mm, while the main axis diameter was 55.41 ± 1.57 mm.

3.2. Drying kinetics modeling

The drying curves for apricot at five temperatures can be seen in Figure 1, where MR is a function of drying time. Equilibrium moisture content (Xwe) of about 0.02 g water g⁻¹ dm is achieved at all drying temperatures, being more rapid at a higher temperature. For the drying temperature of 60°C and 80°C, Xwe was reached between 780 and 420 min, respectively, while at temperatures below 50°C the drying time was over 1000 min. Only a falling rate period was observed, similar to that reported by Toğrul and Pehlivan (2003), Bozkır (2006) and López et al. (2010) who worked with apricots and blueberries, respectively.

The values of Dwe obtained for different temperatures used are presented in Table 1. For the apricots samples dried at 40–80°C, Dwe varied within a range of 0.95–4.22 × 10⁻² m² s⁻¹ and obtaining high determination coefficient values, 0.95 < r² < 0.98. These values for Dwe confirm that the drying rate increases as drying temperature is raised. These values were close to those reported by Chong, Law, Cloke, Hii, and Abdullah (2008) for apricot (0.89–1.3 × 10⁻² m² s⁻¹) and grape (7.91–2.5 × 10⁻⁹ m² s⁻¹); Vega-Gálvez, Lara, Flores, Di Scala, and Lemus-Mondaca (2012) for blueberries (9.51–17.71 × 10⁻¹⁰ m² s⁻¹); and Doymaz and Ismail (2011) for sweet cherry (0.55–1.54 × 10⁻⁹ m² s⁻¹). As to ANOVA analyses conducted on Dwe values at a confidence level of 95%, a p < 0.05 was obtained, concluding a significant effect of drying temperature on Dwe and likewise five homogenous groups were identified for Dwe (40°C, 50°C, 60°C, 70°C, and 80°C) by MRT.

The drying kinetics had an exponential tendency that could be adjusted to the Weibull distribution model, as can be seen in Figure 1, where it is possible to observe the close agreement between the experimental and predicted data for all drying conditions. In Table 1, the kinetic constants of the Weibull model, related to the process variables by statistical analysis are given as average values for all experiments. The Weibull drying constant β was significantly affected (p < 0.05) during drying, showing a decrease with increasing drying temperature, as can be seen in Table 1. The β parameter is usually related to the rate of mass transfer at the beginning of the drying process, as reported by Corzo, Bracho, Pereira, and Vásquez (2008) and this corresponds to the reciprocal value of the effective diffusion coefficient (García-Pascual, Sanjuán, Melis, & Mulet, 2006; Corzo et al., 2008; Miranda et al., 2010). The Weibull model was found valid for mushrooms (García-Pascual et al., 2006), Coroba slices (Corzo et al., 2008) and Aloe Vera gel (Miranda et al. 2010). As a rate parameter, β is temperature sensitive and β⁻¹ can be expected to follow an Arrhenius-type behavior (Cunha, Oliveira, & Oliveira, 1998). The results show that both β and α were affected by air temperature. Values of α ranged from 1.026 to 1.199, the shape parameter for a fractional amount of moisture content increased (p < 0.05) with air temperature increase. Thus, the lower the α value, the faster the drying rate at the beginning is. The model applied to apricots had coefficients of determination near to 1 (r² > 0.97) and very low chi-square (χ² < 0.0014) values for all drying temperatures. These values indicated a good fit of the experimental data to the model, suggesting that the Weibull model is suitable for predicting moisture content of apricots.
3.3. Microstructural changes

Apricot structural changes were observed by Cryo-SEM. Figure 2(a) shows the cell structure of fresh apricot and Figure 2(b,c) show morphological and microstructural changes observed in rehydrated samples coming from apricots dried at 40°C and 80°C respectively. In the scanning electron microscopy (SEM) images for fresh apricots, the cell walls from the mesocarp and the intercellular connections can be clearly distinguished (Figure 2(a)). The effect of drying temperature on the tissue structure of rehydrated apricot caused broken cellular membranes and damaged cell walls, appearing in many places interrupted and so, the cells became slightly more irregular in shape. The most important of these phenomena is cell shrinkage, which causes a major modification in the global structure of the product, and it is directly related to the loss of water during drying (Ramírez et al., 2011). Convective hot air drying affects the microstructure of apricot showing a higher cellular tissue collapse and shrinkage as the drying temperature increases. The cells of the mesocarp of 40ºC air-dried samples (Figure 2(b)) still maintained their individuality and intact cell walls were even found. As the intensity of the applied power increased, the drying effects became more intense. As a consequence, a highly compacted tissue appeared in 80°C dried samples (Figure 2(c)). Thus, the microstructure information could also be a huge help when it comes to understand both bioavailability and binding of phenolic compounds within a food previously processed (Balasundram, Sundram, & Samman, 2006). Therefore, the operational variables (e.g. temperature) of the drying processes must be considered.

3.4. Surface color

The CIE color parameters $L^*$, $a^*$, and $b^*$ have been widely used to describe the color properties of fruit and vegetable products. The color variables have been related to the types and quantities of some components present in foods (Akin et al., 2008; Di Scala et al., 2011). Mean color values of fresh and dried apricots are shown in Figure 3. For the fresh apricot samples chromatic parameters $L^*$, $a^*$, and $b^*$ of 54.44, 23.67 and 59.84, respectively, were determined. The color coordinates $L^*$, $a^*$ and $b^*$ show significant differences between the fresh and dried samples (p < 0.05). During drying below 60°C and above 70°C, the brightness parameter $L^*$ decreased significantly. At the drying temperature of 70°C, no significant change in brightness was observed, while at 60°C only a slight change in brightness occurred. Below 60°C the effect of drying time predominate over temperature, while above 70°C, the short drying time cannot compensate the darkening effect of temperature as a consequence of the increasing rate of non-enzymatic browning (NEB) reactions (Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, 2001).

Furthermore, the effect of decreasing water activity in amorphous dehydrated systems can be decisive on the NEB reaction rate (Acevedo, Briones, Buera, & Aguilera, 2008). Coordinate $a^*$ (greenness–redness) showed an increasing tendency when increasing drying temperature. The increase of $a^*$ value generally denotes a variation towards the red chroma, typical of the browning phenomena (García-Martínez et al., 2013). The relatively highest changes in the magnitude of the coordinate $a^*$ at 60°C and 70°C showed an enhancement in the reddish color while maintaining the glossiness of the apricots.
Coordinate $b^*$ (blueness-yellowness) decreased in the dried apricot samples, indicating that the yellow color characteristic of fruit is affected by drying temperature. A higher loss in yellow color is observed at 40°C and 50°C which is congruent with the loss of brightness. Akin et al. (2008) have reported similar changes in the chromatic parameters of different varieties of apricot.

Although a desirable color of the dried apricots may be achieved, a total color difference ($\Delta E$) between the processed and unprocessed fruit is unavoidable. According to Chen (2008), appreciable differences in a range of $5 < \Delta E < 25$ can occur, as observed for dried pepino fruits. In this study, the lowest $\Delta E$ value of 9.0 was determined in apricots dried at 80°C and at drying temperatures at 40°C and 50°C, the $\Delta E$ values were higher than those achieved above 60°C, showing the preponderance of drying time over temperature. However, the $\Delta E$ values achieved at any of the assayed temperatures did not exceed 16.6 and were therefore lower than a value of $\Delta E > 24$ reported by García-Martínez et al. (2013) for Spanish apricots.

### 3.5. Total phenolic content (TPC) and flavonoid contents (TFC)

In Table 2, changes in TPC and TFC as well as in antioxidant capacity determined by DPPH radical scavenging assays can be seen. The TPC found in fresh apricot samples was in a range lower than the values reported by Akin et al. (2008) and Ali et al. (2011) with 4452.7 mg GAE 100 g$^{-1}$. These differences may be due to a difference in the variety of apricots or to the complexity of the group of phenolic compounds as well as to extracting methods and analyses (Balasundram et al., 2006). TPC of dried apricots at the five air-drying temperatures decreased down a 73% at 60°C, compared to the fresh sample content. During drying, binding of polyphenols with other compounds such as proteins may occur (Mrad, Boudhrioua, Kechaou, Courtois, & Bonazzi, 2012b) or the chemical structure of the polyphenols can also be altered (Agostini, Jimenez, Ramon, & Gomez, 2004), leading to an unavoidable decrease in TPC.

As observed in Table 2, a flavonoid content of 2104.7 mg CE 100 g$^{-1}$ dm was determined in the fresh apricot. A significant ($p < 0.05$) decrease in total flavonoids occurred after drying at all assayed temperatures; thus, a decrease of total flavonoids of about 61% to 80% compared to the fresh apricot was observed, where no significant difference ($p > 0.05$) was found at 50°C, 70°C, and 80°C. These results are in agreement with the results obtained in the cellular microstructure since the greatest cellular damages were observed at higher drying temperatures. The best retention of TPC and TFC was obtained at 40°C, in spite of a long drying time (over 1500 min). Some authors have also reported a decrease in the phenolic compounds of dried apricots that also
attributed to a polyphenoloxidase (PPO) enzymatic activity. It has been found that during the dehydration process, PPO activity remains high for longer periods when the drying temperature is around 55–60°C while, only shorter exposure periods are needed to inactivate the enzyme at temperatures of 75–80°C (Igual et al., 2012; Madrau et al., 2009).

3.6. Determination of antioxidant capacity

Apricots contain a wide variety of phytochemicals that function as antioxidants. This study evaluated the changes in antioxidant capacity by DPPH in apricots as influenced by hot air drying at different temperatures. In Table 2, a significant (p < 0.05) decrease of DPPH assays was observed, compared to fresh samples (7822.9 μmoles TE 100 g⁻¹ dm), where the highest value in dried samples was 2185.6 μmoles TE 100 g⁻¹ dm at 40°C. This behavior is similar to that observed on TPC and TFC. The results concerning antioxidant capacity in the current study are comparable to previous findings by Incedayi, Tamer, Sinir, Suna, and Çopur (2016) in apricots affected by a higher temperature and power level treatments caused less inhibition on DPPH radical.

3.7. Identification of phenolic compounds

The chromatogram of the HPLC analysis revealed the presence of five different phenolic compounds (chlorogenic acid, syringic acid, quercetin 3-rutinoside, catechin, and epicatechin) in the apricot fruit samples. The phenolic compounds were detected only in the free form, as shown in Table 3. It has nevertheless to be borne in mind that the subspecies, varieties, location, weather, year together with genotype is known to influence not only the total carotenoid content but also the proportions of each carotenoid species (i.e. R- and α-carotene) as is the case with apricots, peaches and plums (Gil, Tomás-Barberán, Hess-Pierce, & Kader, 2002; Ruiz, Egea, Tomás-Barberá and Gil, 2005).

Catechin was the predominant phenolic compound in all apricot samples under study obtaining values from 70.1 to 129.6 mg 100 g⁻¹ dm, followed by quercetin 3-rutinoside and epicatechin, which belong to the flavonoids group. The predominant phenolic acid identified in apricot fruit was the chlorogenic acid with values from 18.4 to 37.1 mg 100 g⁻¹ dm, which are consistent with reports of several authors (Dragovic-Uzelac et al., 2007; Igual et al., 2012; Madrau et al., 2009). While the main compounds belong to the hydroxycinnamic acids derivatives, it was found neither ferulic acid nor coumaric acid.

In general, polyphenolic contents are higher, compared to data reported from other apricot cultivars (Dragovic-Uzelac et al., 2007; Igual et al., 2012; Madrau et al., 2009). The differences between fresh fruit and dried samples were statistically significant (p < 0.05), Table 3 shows that all dried samples had higher phenolic compound contents than the fresh samples, unlike to TPC, TFC and DPPH methodologies. Igual et al. (2012) explain that may be because the use of temperature generates more and better extraction of these compounds, as it happens with the dried products. The highest values of phenolic acid were observed at 60°C however, there are tendencies to a higher flavonoid retention at lower drying temperatures. It is interesting to note that the changes in the catechin and epicatechin contents occurring in the dried samples correspond to a decrease in content when increasing temperature, where the highest values of flavonoids were observed at 40°C, being independent of the long drying time, whose values agree with the highest values being observed in TFC.

3.8. Vitamin C and β-carotene contents

Vitamin C, an important antioxidant and a quality indicator of post-harvest shelf life, is of great importance in human diet due to its numerous roles in the body. About 91% of ascorbic acid in the human diet comes from fruits and vegetables (Ali et al., 2011). The effect of air-drying temperature on vitamin C content of apricot is shown in Figure 4. The vitamin C content determined in the dehydrated samples were found in a range from 4.8 to 13.5 mg 100 g⁻¹ dm, which was a significant (p < 0.05) decrease with respect to the fresh apricot (18.9 mg 100 g⁻¹ dm), being the highest value at 80°C. Similar ranges of value have been reported in the literature: Chauhan, Tyagi, and Singh (2001) reported

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Table 2. Total phenolic content (TPC), total flavonoid content (TFC) and antioxidant capacity by DPPH assay in fresh and dried apricots.

| Temperatures (°C) | TPC | TFC | DPPH |
|------------------|-----|-----|------|
| Fresh            | 4452.7 ± 339.9 | 2104.7 ± 150.8 | 7822.9 ± 72.6 |
| 40               | 1654.0 ± 108.8 | 812.2 ± 16.2    | 2185.6 ± 72.1  |
| 50               | 1354.3 ± 39.3  | 413.6 ± 21.4    | 1790.0 ± 159.9 |
| 60               | 1195.5 ± 62.5  | 682.9 ± 22.5    | 1651.4 ± 121.8 |
| 70               | 1473.6 ± 30.7  | 458.1 ± 19.3    | 1622.7 ± 159.9 |
| 80               | 1401.1 ± 53.7  | 481.3 ± 24.3    | 1464.1 ± 121.8 |

Results are mean ± SD. Different letters in the same column indicate that values are significantly different (p < 0.05). 1 Total phenolic content: mg Gallic acid equivalents (GAE) 100 g⁻¹ dm⁻¹. 2 Total Flavonoid content: mg Catechin equivalents (CE) 100 g⁻¹ dm⁻¹. 3 2,2-Diphenyl-1-picryl-hydrazyl method: μmoles Trolox equivalent (TE) 100 g⁻¹ dm⁻¹. Los resultados son medios ± desviaciones estándar. Letras diferentes en la misma columna indican que los valores son significativamente diferentes (p < 0.05). 1 Contenido fenólico total: mg ácido gálico equivalentes (GAE) g⁻¹ dm⁻¹. 2 Contenido flavonoide total: mg Catequina equivalentes (CE) 100 g⁻¹ dm⁻¹. 3 Método 2,2-Diphenil-1-picryl-hidrazilo: μmoles Trolox equivalente (TE) 100 g⁻¹ dm⁻¹.

Table 3. Free phenolic compounds in fresh and dried apricots.

| Phenolic compounds | Fresh (mg 100 g⁻¹ dm⁻¹) | 40 | 50 | 60 | 70 | 80 |
|--------------------|-------------------------|----|----|----|----|----|
| Chlorogenic acid   | 18.4 ± 1.6              | 33.8 ± 1.2 | 20.5 ± 0.1 | 37.1 ± 1.0 | 19.1 ± 0.8 | 35.1 ± 1.4 |
| Syringic acid      | 3.7 ± 0.3               | 5.6 ± 0.1 | 3.8 ± 0.1   | 6.3 ± 0.3   | 4.0 ± 0.3   | 4.6 ± 0.2   |
| Rutin Hydrate      | 49.4 ± 3.1              | 37.0 ± 0.2 | 64.5 ± 2.8 | 43.9 ± 2.9 | 52.1 ± 2.8 | 50.0 ± 4.5 |
| Catechin           | 70.1 ± 0.5              | 129.6 ± 2.2 | 83.1 ± 5.1 | 96.8 ± 1.1 | 91.5 ± 5.8 | 85.2 ± 4.0 |
| Epicatechin        | 48.4 ± 3.6              | 60.1 ± 5.8 | 35.9 ± 1.2 | 50.4 ± 0.2 | 45.3 ± 2.2 | 41.1 ± 1.8 |

Values are mean ± SD, n = 3. Different letters in the same row indicate that values are significantly different (p < 0.05). Los valores son medias desviación estándar, n = 3. Letras diferentes en la misma fila indican que los valores son diferentes significativamente (p < 0.05).
a range of 5–19 mg 100 g⁻¹ dm⁻¹, Madrâu et al. (2009) reported 2.3–28.6 mg 100 g⁻¹ dm⁻¹, and García-Martínez et al. (2013) reported 6.7–17.5 mg 100 g⁻¹ dm⁻¹. There are also other reported values for Turkish and Pakistani apricots: Akin et al. (2008) reported 20.6 and 96.8 mg 100 g⁻¹ dm⁻¹, while Ali et al. (2011) reported 67.39 to 90.94 mg 100 g⁻¹ dm⁻¹. The highest loss of vitamin C was around 74% of the original value and was observed at lower drying temperatures (40°C and 50°C), which may be due to the longer drying times and therefore a longer exposure to degradation.

Apricot is known to be a rich source of carotenoids, especially β-carotene, which represents 50% of the total carotenoids in the fruit (Akin et al., 2008; Ali et al., 2011). The effect of air-drying temperature on β-carotene is shown in Figure 4. The initial content of β-carotene (14.2 ± 0.20 mg 100 g⁻¹ dm⁻¹) in the fresh sample was higher than that reported by Dragovic-Uzelac et al. (2007) for other apricot cultivars, but within values reported by Akin et al. (2008), Ali et al. (2011) and García-Martínez et al. (2013). Regarding the effects of air-drying temperature on β-carotene content at 60°C, this compound is retained better compared to the other treatments. Furthermore, the drying at 60 and 80°C did not show any significant differences (p < 0.05). In all treatments, a decrease of carotenoid content is observed (p < 0.05), being the β-carotene content at 40°C the most affected by the long drying time (53% loss). The carotenoids of fruit act as antioxidants and protect the cell membrane from oxidative damage. In addition, variations among carotenoid contents are attributed to climate, variety, geographical origin, harvest year and the methods of cultivation (Ali et al., 2011).

### 3.9. Sugar content

Apricot contains important amounts of sugars in the ripe state, and through dehydration, during storage or drying processes there is a further concentration of sugars (Ali et al., 2011). The content of individual sugars in the fresh and the dried apricot samples is shown in Table 4, being sucrose, glucose, fructose, and sorbitol as the major sugars. Sugar contents of fresh and dried apricot at different temperatures were found significantly different (p < 0.05). Sucrose was found as the predominant sugar present in all apricot samples, and its content in the dried apricots varied from 20.2 to 28.5 g 100 g⁻¹ dm⁻¹. The highest glucose and fructose contents were found in the samples dried at 40°C (7.9 and 10.6 g 100 g⁻¹ dm⁻¹, respectively). It was also found that in all the apricot samples a considerable amount of sorbitol ranging from 3.3 to 8.9 g 100 g⁻¹ dm⁻¹ was present, being the highest at 70°C. Akin et al. (2008) reported sorbitol, as being one of the alcohol sugars that is more beneficial than other sugars with regard to diet control (reducing caloric intake) and dental health. It also improves the taste and texture of fruits. As compared to available data in literature, sugar contents of Chilean apricots were found considerably higher than those apricots grown in other countries (Akin et al., 2008; Forni, Sornani, Scalise, & Torreggiani, 1997; Katona, Sass, & Monar-Perl, 1999), due to different climatic conditions and other factors.

### 4. Conclusions

Effective moisture diffusivity of apricot fruits increased from 0.95 to 4.22 × 10⁻⁹ m² s⁻¹ with the increase in drying temperature, whilst the Weibull equation showed the best fit quality during modeling of drying kinetics. The best retention of TPC and TFC was obtained at 40°C, and high values for
DPPH assays. Chlorogenic, syringic, quercetin 3-rutinoside, catechin and epicatechin were identified, where the flavonoid catechin was predominant. Apricot drying resulted in a low vitamin C and β-carotene degradation at 80°C and 60°C, respectively. Sucrose was the predominant sugar (p < 0.05) in apricot. As to microstructure, a lower cell damage at 40°C was showed than at higher drying temperatures. High temperatures led to a modification on fruit surface color as indicated through the ΔE parameter (p < 0.05). Thus, the results of the present study can be seen as a valuable tool to harness the drying process of apricots fruit, in order to minimize adverse changes on both bioactive components and structural properties. Finally, we can recommend evaluating the influence of other factors of interest both the same fruit (postharvest time, other varieties, and some pre-treatment) and drying process (relative humidity, different drying methods) and its associated effects on rehydration characteristics, sensorial analysis, among others.

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