International Journal of
Food Science & Technology
www.ifst.org
International Journal of Food Science and Technology 2011

Original article

Changes of quality characteristics of pepino fruit (*Solanum muricatum Ait*) during convective drying

Karina Di Scala,[1,2]*Antonio Vega-Gálvez,[3,4] Elsa Uribe,[3] Romina Oyanadel,[3] Margarita Miranda,[3] Judith Vergara,[3] Issis Quispe[3] & Roberto Lemus-Mondaca[3,5]

1 Food Engineering Research Group, Universidad Nacional de Mar del Plata, Facultad de Ingeniería, Av. Juan B. Justo 4302, 7600, Mar del Plata, Argentina
2 CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas), Buenos Aires, Argentina
3 Department of Food Engineering. Universidad de La Serena, Av. Raúl Bitrán s/n, Box 599, La Serena, Chile
4 CEAZA, Center for Advanced Studies in Arid Zones, Universidad de La Serena, Av. Raúl Bitrán s/n, Box 599, La Serena, Chile
5 Department of Mechanical Engineering, Universidad de Santiago de Chile, Av. Lib. Bdo. O'Higgins 3363, Santiago, Chile

(Received 24 September 2010; Accepted in revised form 20 December 2010)

Summary Quality assessment of pepino fruit preserved through convective dehydration was investigated in this work. The effect of process temperature (50, 60, 70, 80 and 90 °C) on physicochemical properties, colour, non-enzymatic browning, vitamin C, total phenolic content, antioxidant activity and firmness of the fruit were considered. When comparing the fresh with the corresponding dehydrated pepino samples, it was shown that the drying conditions resulted in important reductions of proteins and crude fibres. Discoloration of fruit was noticeable for all treatments due to effects of non-enzymatic browning and changes in chromatic coordinates leading to a modification of the original colour. Regarding vitamin C and total phenolic content, an increase of drying temperature resulted in a considerable reduction of both initial compounds contents. Antioxidant activity showed an important decrease especially at low temperatures (e.g. 50 °C). Softening of the dried product was observed for all the treatments indicating structural modifications of the fruit due to thermal process.

Keywords Antioxidant activity, ascorbic acid, firmness, hot air-drying, non-enzymatic browning, pepino fruit.

Introduction

Today, the production of dried fruits is widespread. Dried fruit is widely used by the confectionery, baking, and sweets industries (Barta, 2006).

Pepino (*Solanum muricatum Ait*.) contains a high percentage of their fresh weight as water (92%), it is low in calories, very rich in minerals and contains vitamins like thiamine, niacin, riboflavin and ascorbic acid (vitamin C), ideal for a number of metabolic and antioxidant reactions (Díaz, 2006). Many research studies have demonstrated that fruits contain various components with antioxidant activity, which are responsible for beneficial health effects (Cartron *et al*., 2001; Giovanelli & Buratti, 2009; Locatelli *et al*., 2009). In particular, vitamin C and polyphenols have shown strong antioxidant capacity against free radicals which are involved in the pathogenesis of several chronical and degenerative diseases (Kuskoski *et al*., 2005; Seifried, 2007; Wang & Stoner, 2008; Sun *et al*., 2009). In addition, the first quality judgment made by a consumer on a food at the point of sale is its visual appearance as well as texture (Vega-Gálvez *et al*., 2009; Lopez *et al*., 2010). Therefore, due to its appearance and high content of phytochemicals, pepino lends itself to the production of a number of processed products such as dehydrated products, amongst others (Huyskens-Keil *et al*., 2006; Uribe *et al*., 2009).

Hot air drying is one of most widely used technology for food preservation (Vega-Gálvez *et al*., 2008, 2009). This unit operation is applied to reduce the water content of products such as fruits, vegetables, agricultural and herbal products, etc. after harvest. The purpose of reducing the water content is to prolong the shelf-life of biological products by reducing the water activity to a level low enough where growth of microorganisms, enzymatic reactions, and other deteriorative reactions is inhibited (Mujumdar & Law, 2010). However, it is well known that during food dehydration

*Correspondent: Fax: +54 2234810046;
e-mail: kdiscala@fi.mdp.edu.ar

doi:10.1111/j.1365-2621.2011.02555.x

some physico-chemical, nutritional and organoleptical changes can happen. Several works have reported modifications on physico-chemical properties (Attanasio *et al.*, 2004; Miranda *et al.*, 2009); colour (Krokida *et al.*, 2001; Luangmalawat *et al.*, 2008; Cernîşev, 2010); vitamin C (Sablani, 2006; Di Scala & Crapiste, 2008; Vega-Gálvez *et al.*, 2009) and firmness (Vega-Gálvez *et al.*, 2009; López *et al.*, 2010) during dehydration. Thus, in preserving fruits for extending its shelf life and minimising quality loss, it is important that the denaturation or damage of the bioactive ingredients by the preservation methods is minimised as well (Devahastin & Niamnuy, 2010; Fernandes *et al.*, 2010). Concerted attempts have been made to alleviate the previously mentioned food modifications. In this sense, the optimisation of the dehydration process in the agro-food industry involves selection of control variables involved in the process itself, good experimental designs as well as statistical programmes to help obtaining a higher yield from the operational and capital investment points of view leading to a final product with high quality (Di Scala & Crapiste, 2008; Vega-Gálvez *et al.*, 2009). Therefore, the aim of the present work is to study the effects of air drying temperature on the most relevant pepino quality characteristics such as physicochemical, colour, non enzymatic browning, antioxidant capacity (vitamin C and total phenolic compounds) as well as firmness during convective hot air dehydration.

Materials and methods

Preparation of raw material and drying process

Pepino fruits (*Solanum muricatum Ait.*) were acquired at a local market in the region of Coquimbo, Chile. The pepino fruits were selected by colour, size and state of ripeness according to a visual inspection with no signs of mechanical damage, and stored at 4 °C before processing. The pepino fruits were cut in slabs of 4.0 ± 0.2 mm in thickness. The hot-air drying process was carried out in a convective dryer designed and built at the Department of Food Engineering of Universidad de La Serena, Chile (Uribe *et al.*, 2009). Dehydration was performed at five temperatures 50, 60, 70, 80 and 90 °C, with a constant air flow rate of 2.0 ± 0.1 m s^{-1} and a raw material load density of 10.2 kg m^{-2}. Samples of 50.0 ± 0.1 g of pepino fruit slabs were placed as a thin layer in a stainless steel basket and weighed in a digital balance (OHAUS, model SP402, New Jersey, USA) with an accuracy of ±0.01 g. Hot air flowed perpendicularly through the samples. The samples were dried until they reached a constant weight (equilibrium condition). Drying times ranged between 180 and 600 min depending on process temperature (Uribe *et al.*, 2009). Then, they were removed and vacuum-sealed in low density polyethylene bags for storage until further processing. Each drying experiment was carried out in triplicate.

Quality parameters

Physicochemical analyses

The crude protein content was determined using the Kjeldahl method with a conversion factor of 6.25 (AOAC No.960.52). The lipid content was analysed gravimetrically following Soxhlet extraction (AOAC No. 960.39). The crude fibre was estimated by acid/alkaline hydrolysis of insoluble residues (AOAC No. 962.09). The crude ash content was estimated by incineration in a muffle furnace at 550 °C (AOAC No. 923.03). The equilibrium moisture content was determined by means of AOAC method No. 934.06 (AOAC, 1990). The pH was measured, previous calibration of the instrument with a buffer solution of pH 4.0 and 7.0, using an EXTECH Instruments microcomputer pH-vision 246072 (Waltham, MA, USA); the percentage of titratable acidity was expressed as g citric acid/100 g sample. The water activity (a_w) was measured at 25 °C by means of a water activity instrument (Novasina, model TH-500, Pfäffikon, Switzerland). Soluble solids (ºBrix) were measured using a refractometer (ABBE, 1T, Tokio, Japan). All measurements were carried out in triplicate.

Non-enzymatic browning

Determination of non-enzymatic browning compounds (NEB) solubilised in the rehydration water followed the methodology applied in the work of Vega-Gálvez *et al.* (2009) based on Meydav (1977). The rehydration water was first clarified by centrifugation at $3200 \times \boldsymbol{g}$ for 10 min. The supernatant was then diluted 1:1 with 95% ethanol (Sigma Chemical CO., St. Louis, MO, USA), homogenised further, and centrifuged at $4000 \times \boldsymbol{g}$ for 10 min (Greetmed, GT211-80-2, Hejiang, China). The absorbance of the supernatant was read at a wavelength of 420 nm (Spectronic^R 20 Genesys^{TM} Spectrophotometer, Rochester, NY, USA) following calibration of the equipment with a blank (1:1 dilution of distilled water and 95% ethanol) using quartz cuvettes. All measures were done in triplicate. NEB was expressed as Abs g^{-1} d.m.

Surface colour

The colours of pepino samples were measured by a colorimeter (HunterLab, MiniScan^{TM} XE Plus, Reston, VA, USA). Colour was expressed in CIE L^* (whiteness or brightness), a^* (redness/greenness) and b^* (yellowness/blueness) coordinates, standard illuminant D_{65} and observer 10° (Vega-Gálvez *et al.*, 2008). Five replicate measurements were performed and results were averaged. The total colour difference (ΔE) was calculated

using eqn 1, where L_o, a_o and b_o are the control values for fresh pepino fruit.

$$\Delta E = \left[(a* - a_0)^2 + (b* - b_0)^2 + (L* - L_0)^2\right]^{0.5} \quad (1)$$

Vitamin C

The determination of vitamin C was performed by certification of NBS (N - Bromosuccinimide) according to Barakat *et al*. (1955) with modifications. The oxidising agent (NBS) was standardised by taking an aliquot of 10 mL of a standard solution of ascorbic acid (0.2 mg mL^{-1}), which is placed in a 250 mL Erlenmeyer flask containing 2 mL of a solution of KI (4%), 0.8 mL of a solution of acetic acid (10%), drops of a solution of starch (1%) as indicator and 12 mL of distilled water, then titrated with a solution of NBS (0.2 g L^{-1}). The end point was reached when a permanent blue colour was observed. For the determination of ascorbic acid in fresh and rehydrated samples, 0.2 g oxalic acid was added, crushed, homogenised and filtered. The samples solution was placed in a Erlenmeyer flask containing 5 mL of KI solution, 2 mL of acetic acid solution, drops of starch solution and 30 mL of distilled water, then titrated with the NBS solution. Each determination was performed in triplicate. The content of Vitamin C, expressed as mg Vitamin C 100 g^{-1} d. m, was calculated as follows:

$$\text{Vit C} = \left(\frac{2AA \times B)}{T \times M)}\right) \times 100 \quad (2)$$

where T (mL) is the volume of NBS of the standard solution of 2 mg of Vitamin C (AA); B (mL) is the volume of NBS corresponding to the sample and M (g) is the sample mass.

Total phenolic content

Total phenolic content (TPC) were determined calorimetrically using the Folin-Ciocalteau reagent (FC) according to Chuah *et al*. (2008) with modifications. 0.5 mL aliquot of the quinoa extract solution is transferred to a glass tube; 0.5 mL of reactive FC is added after 5 min; and 2 mL of Na_2CO_3 solution (200 mg mL^{-1}) were added and shaken. The sample was then mixed on a vortex mixer and the reaction proceeded for 15 min at ambient temperature. Then, 10 mL of ultrapure water were added and the formed precipitate was removed by centrifugation during 5 min at $4000 \times \boldsymbol{g}$. Finally, the absorbance was measured in a spectrophotometer (Spectronic® 20 GenesysTM131, Chicago, IL, USA) at 725 nm and compared to a gallic acid (GA) calibration curve. Results were expressed as mg GA 100 g^{-1} dry matter. All reagents were purchased from Merck (Merck KGaA, Darmstadt, Germany). All measurements were done in triplicate.

Antioxidant activity

Free radical scavenging activity of the samples was determined using the 2,2,-diphenyl-2-picryl-hydrazyl (DPPH) method (Turkmen *et al*., 2005) with some modifications. Different dilutions of the extracts were prepared in triplicate. An aliquot of 2 mL of 0.15 mM DPPH radical in ethanol was added to a test tube with 1 mL of the sample extract. The reaction mixture was vortex-mixed for 30 s and left to stand at room temperature in the dark for 20 min. The absorbance was measured at 517 nm, using a spectrophotometer (Spectronic® 20 Genesys™, IL, USA). 80% (v v^{-1}) ethanol was used to calibrate the spectrophotometer. Control sample was prepared without adding extract. All solvents and reagents were purchased from Sigma (Sigma Chemical Co., St Louis, MO, USA). Total antioxidant activity (TAA) was expressed as the percentage inhibition of the DPPH radical and was determined by eqn 3:

$$\%\ \text{TAA} = \left(1 - \frac{\text{Abs}_{\text{sample}}}{\text{Abs}_{\text{control}}}\right) \times 100 \quad (3)$$

where TAA is the total antioxidant activity and Abs is the absorbance. IC_{50}, which is the concentration required to obtain a 50% antioxidant capacity, is typically employed to express the antioxidant activity and to compare the antioxidant capacity of various samples. IC_{50} was determined from a graph of antioxidant capacity (%) against extract concentration (μg mL^{-1} sample).

Firmness

Firmness, which is the maximum force applied to puncture the pepino fruit tissue, was measured as an indicator of texture. Firmness of samples was measured using a Texture Analyzer (Texture Technologies Corp., TA, XT2, Scardale, NY, USA). The puncture diameter was 2 mm, with a travel distance of 20 mm and 1.7 mm s^{-1} test speed. The maximum force was measured by making one puncture in each rehydrated pepino fruit sample, using ten slabs per treatment. The mean value of maximum firmness for each treatment was then calculated and the results were expressed as N mm^{-1}.

Statistical analysis

The effect of temperature on each quality parameter was estimated using Statgraphics Plus 5.1® (Statistical Graphics Corp., Herndon, VA, USA). The results were

analysed by an analysis of variance (ANOVA). Differences between the media were analysed using the least significant difference (LSD) test with a confidence interval of 95% ($P < 0.05$). The multiple range test (MRT) included in the statistical programme was used to demonstrate the existence of homogeneous groups within each of the parameters.

Results and discussion

Physicochemical properties

Table 1 shows the mean values and standard deviations of the proximate analysis of pepino fruit including moisture, protein, fat, crude fibre and ash of both fresh and dried samples. In the same table, mean values and standard deviations of the moisture content, water activity, soluble solids, % acidity and pH of both fresh and dry-rehydrated pepino fruit samples are also reported. Significant differences were found between temperature and the properties mentioned ($P < 0.05$). Similar results were reported in previous works (Ahumada & Cantwell, 1996; Galletti *et al*., 2006). As expected, the fresh pepino showed a water activity value of 0.950 indicating its susceptibility to microbial spoilage as well as enzymatic and oxidation reactions. Nevertheless, after dehydration all dehydrated samples showed $a_w < 0.167$ presenting more stability towards spoilage during storage (Barbosa-Canovas & Vega-Mercado, 2000).

When analysing Table 1, the chemical composition of the dehydrated pepino samples from the lowest (50 °C) to the highest process temperatures (90 °C) presented comparable values for each chemical compounds. However, when comparing the fresh with the corresponding dehydrated pepino samples, it was shown that the drying operation leads to reductions of 92% in proteins, 35% in fat and 57% in crude fibre. The loss of protein could be due to denaturation followed by the release of amino acids from the proteins which could react with other chemicals compounds via the Maillard reaction (Perera, 2005; Leite *et al*., 2007; Miranda *et al*., 2009). The decrease in lipid content may be due to either enzymatic hydrolysis during the first drying period or lipid oxidation because of thermal treatment (Perera, 2005). Regarding to the loss of crude fibre, the decrease of the content for these constituents might be due to thermal degradation resulting in disruption of the polysaccharides network of the cell wall (Miranda *et al*., 2010).

Colour

The colour parameters L^*, a^* and b^* have been widely used to describe colour changes during thermal processing of agricultural products. These colour variables have been related to the types and quantities of some components present in these products (Bahloul *et al*., 2009). Mean colour values of fresh and dried pepino are shown in Fig. 1. Fresh pepino fruit chromatic parameters a^*, b^* and L^* were $^{-}2.45$, 48.18 and 78.22, respectively. From the point of view of colour coordinates a^*, b^* and L^* there are significant differences between the fresh and dried samples ($P < 0.05$). All treatments decreased the brightness (L^*) indicating that fresh pepino presented a darker colour compared to the dry-rehydrated samples. There were reports that the higher the degree of browning found, the lower the L^* value of the samples (Ergünes & Tarhan, 2006; Prathapan *et al*., 2009). Moreover, dehydrated pepino fruits become darker probably due to a larger extension of the Maillard reaction (Manzocco *et al*., 2001; Vega-Gálvez *et al*., 2009). These chemical reactions are consequence of the presence of reducing sugars and with amino acids in the material being dehydrated (Perera, 2005; Huyskens-Keil *et al*., 2006). Furthermore, effect of decreasing water activity in amorphous systems (dehydrated systems) is a decisive factor in the NEB reaction rate

Table 1 Physicochemical characterisation of fresh and dehydrated pepino fruit (g 100 g^{-1} d. m.)

Parameters	Fresh	50 °C	60 °C	70 °C	80 °C	90 °C
Moisture (g/g)	11.78 ± 0.514^{a}	0.23 ± 0.064^{b}	0.16 ± 0.010^{b}	0.08 ± 0.109^{b}	0.06 ± 0.029^{b}	0.02 ± 0.008^{b}
Protein* (Nx6.25)	2.52 ± 0.401^{b}	0.27 ± 0.039^{a}	0.21 ± 0.008^{a}	0.28 ± 0.044^{a}	0.25 ± 0.011^{a}	0.20 ± 0.096^{a}
Fat*	2.73 ± 0.461^{bc}	1.75 ± 0.333^{a}	2.22 ± 0.074^{ab}	2.72 ± 0.047^{bc}	3.41 ± 0.482^{d}	3.01 ± 0.249^{cd}
Crude fibre*	9.39 ± 0.260^{c}	5.90 ± 0.927^{b}	6.31 ± 0.227^{b}	5.57 ± 0.449^{b}	5.46 ± 1.198^{b}	3.95 ± 0.378^{a}
Ash*	4.92 ± 0.462^{ab}	6.68 ± 0.280^{d}	6.44 ± 0.086^{d}	5.85 ± 0.191^{c}	4.69 ± 0.391^{a}	5.45 ± 0.397^{bc}
pH†	5.31 ± 0.015^{b}	5.11 ± 0.005^{a}	5.04 ± 0.015^{a}	5.32 ± 0.065^{b}	5.38 ± 0.100^{b}	5.45 ± 0.168^{b}
Acidity† (g citric acid/100 sample	0.09 ± 0.007^{a}	1.09 ± 0.045^{b}	1.25 ± 0.089^{b}	1.18 ± 0.120^{b}	1.23 ± 0.345^{b}	1.09 ± 0.029^{b}
Soluble solids (ºBrix) †	6.26 ± 0.251^{a}	7.63 ± 0.152^{b}	8.00 ± 0.200^{b}	8.56 ± 0.404^{c}	9.16 ± 0.152^{d}	9.06 ± 0.152^{d}
a_w (dimensionless)	0.950 ± 0.001^{f}	0.167 ± 0.002^{e}	0.083 ± 0.004^{d}	0.075 ± 0.002^{c}	0.065 ± 0.001^{b}	0.058 ± 0.002^{a}

Similar letters in the exponential in the same row show there are no significant differences ($P < 0.05$). N: nitrogen.

*Dehydrated samples.

†Rehydrated samples for 24 h before analysis.

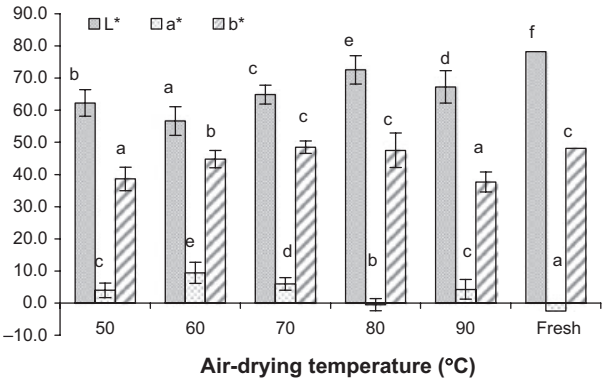

Figure 1 Effect of air-drying temperature on the chromatics coordinates (L^*, a^* and b^*) of fresh and dehydrated pepino fruit samples. Identical letters above the bars indicate no significant difference ($P < 0.05$).

(Acevedo *et al.*, 2008). Coordinate a^* (greenness–redness) presented an increase respect to fresh samples. The increase of a^* value denotes a more red chroma, which is indicative of the browning reaction (Bahloul *et al.*, 2009). Coordinate b^* (blueness–yellowness) showed a slight increase in its value from 50 to 70 °C as a result of generation of brown products due to non-enzymatic reactions, then a decreased is shown.

The effects of air-drying temperature on total colour difference (ΔE) and NEB of pepino fruit are shown in Fig. 2. The lower NEB value was informed at 50 °C compared to the rest of the processes. Treatments at 60 and 90 °C showed comparable NEB-values ($P < 0.05$), perhaps indicating equivalent drying process between the mentioned conditions leading to chemical reactions of fruit pigments degradation (e.g. carotenoids and chlorophylls) (Carabasa-Giribet & Ibarz-Ribas, 2000; Toor & Savage, 2006; Bahloul *et al.*, 2009; Miranda *et al.*, 2009). Some nonenzymatic causes of browning in foods include the Maillard reaction, autooxidation reactions involving phenolic compounds, and the formation of iron–phenol complexes (López-Nicolas & García-Carmona, 2010).

For colour 'sensory' evaluation, ΔE is a very important quantity determining, and according to Chen (2008), appreciable differences were observed in dried pepino since for all thermal treatments $5 < \Delta E < 25$ was verified.

Antioxidant activity

Natural antioxidant definition includes different chemical compounds, such as phenolic compounds, amino acids, peptides, vitamins and enzymes, amongst others. The antioxidant activity of these compounds is due to their ability to scavenge free radicals, donate hydrogen atoms or electron, or chelate metal cations, with a strong structure-activity relationship (Maestri *et al.*, 2006; Bahloul *et al.*, 2009). In particular, vitamin C is considered as an indicador of the quality of food processing due to its low stability during thermal treatments (Podsedek, 2007). Figure 3 shows the content of both vitamin C and TPC of fresh and dehydrated pepino fruits for the five working temperatures. The initial value of TPC and vitamin C for the fresh samples were 925 ± 76 mg GA 100 g^{-1} d. m. and 67.3 ± 0.36 mg AA 100 g^{-1} d. m., respectively. Similar initial values were reported by other authors (Nuez & Ruiz, 1996; Prohens *et al.*, 2004). In this figure, it can be observed that drying temperature had an important influence on both components compared to the fresh samples ($P < 0.05$). There was a clear tendency between temperature and loss of vitamin C, in fact, an increased of this variable led to a notable reduction of the initial vitamin (e.g. at 90 °C the loss of vitamin C is 92%). This could be explained due to irreversible oxidative processes either during drying or rehydration water

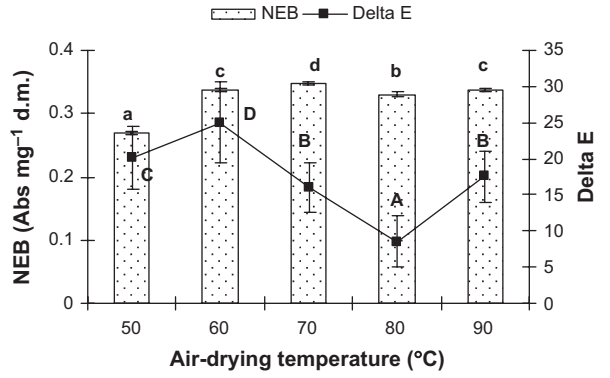

Figure 2 Effect of air-drying temperature on non-enzymatic browning and surface colour (ΔE) for dehydrated pepino fruit samples. Identical letters above the bars indicate no significant difference ($P < 0.05$).

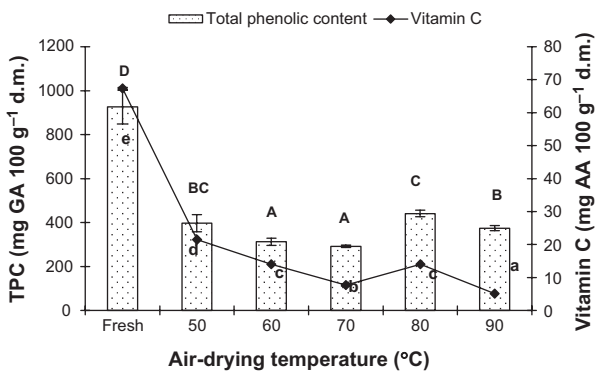

Figure 3 Effect of air-drying temperature on the Vitamin C and TPC of fresh and dehydrated pepino fruit samples. Identical letters above the bars indicate no significant difference ($P < 0.05$).

lixiviation of this water-soluble vitamin (Sigge *et al.*, 2001; Perera, 2005; Vega-Gálvez *et al.*, 2009). Comparable results were reported by other authors when working with aloe vera (Miranda *et al.*, 2009), red pepper (Vega-Gálvez *et al.*, 2009), tomato (Marfil *et al.*, 2008) and kiwi (Kaya *et al.*, 2009).

When analysing the effect of drying temperature on TPC, it was observed that all the treatments resulted in a decrease of TPC compared the fresh samples. In particular, the lowest concentration was observed at 60 and 70 °C. Reductions in TPC during dehydration may be ascribed to the binding of polyphenols with other compounds (proteins) or the alterations in the chemical structure of polyphenols which cannot be extracted and determined by available methods (Chan *et al.*, 2009; Qu *et al.*, 2010). Recent publications have reported that polyphenols can react with amino groups complicating the pathway of the browning reactions and modifying the healthy properties of polyphenols (Manzocco *et al.*, 2001).

The radical scavenging activity was investigated based on air drying temperature ($P < 0.05$) as observed in Fig. 4. The initial IC_{50} was 532.79 ± 24.48 μg mL^{-1}. All the treatments reduced the initial antioxidant capacity of the fruit. The maximum antioxidant capacity loss was observed at 50 °C, where long drying times may promote a decrease of the antioxidant activity (Garau *et al.*, 2007). Moreover, the antioxidant capacity may be related to the amount of vitamin C and TPC, since both act as scavengers of the free radicals produced during oxidation reactions (Kim *et al.*, 2006; Miranda *et al.*, 2009). Concerning the effect of chemical degradation of polyphenols by the Maillard reaction on their antioxidant activity, the chemical oxidation of these compounds is generally responsible for a loss in antioxidant capacity. However, recent observations suggest that partially oxidised polyphenols can exhibit higher antioxidant activity than that of nonoxidised phenols (López-Nicolas & García-Carmona, 2010). In addition, the generation and accumulation of Maillard-derived melanoidins having a varying degree of antioxidant activity could also enhance antioxidant properties at high temperatures (Que *et al.*, 2008; Miranda *et al.*, 2009). Thus, generation and accumulation of compounds having a varying degree of antioxidant activity during food dehydration could also develop antagonistic or synergistic effects with themselves or with the other constituents of samples. These complex chemical interactions that influence functional properties of food are still under investigation.

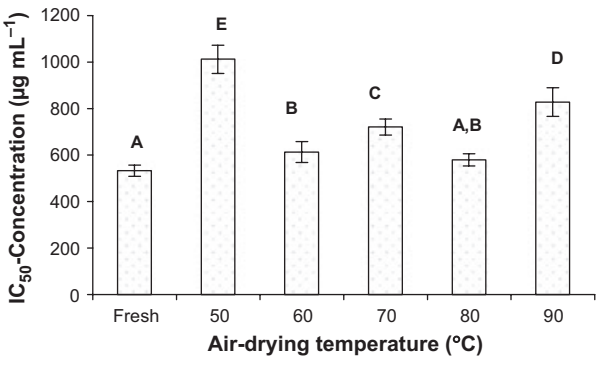

Figure 4 Effect of air-drying temperature on DPPH free radical scavenging activity of fresh and dehydrated pepino fruit samples. Identical letters above the bars indicate no significant difference ($P < 0.05$).

Firmness

Firmness is one of the most desirable attributes in fresh as well as rehydrated fruits (Vega-Gálvez *et al.*, 2009). The behaviour of this physical property affected by drying temperature is illustrated in Fig. 5. It can be observed that process temperature had a notable influence on this textural property presenting a maximum decrease of 51% respect to the fresh sample at 50 and 90 °C ($P < 0.05$). Softening of pepino fruit is reported to be associated with the breakdown of structural cell wall made of carbohydrates, e.g. insoluble pectin, xyloglucan and hemicelluloses located in the middle lamella with a concomitant increase in soluble pectin. These changes in pectic substances result in weakening of the cell walls and reduction of the cohesive forces binding cells together (Prohens *et al.*, 2004; Huyskens-Keil *et al.*, 2006). Similar behaviour during drying was also reported by other researchers working with cherry tomato (Heredia *et al.*, 2007), apples (Acevedo *et al.*, 2008), pepper (Vega-Gálvez *et al.*, 2009) and blueberries (López *et al.*, 2009).

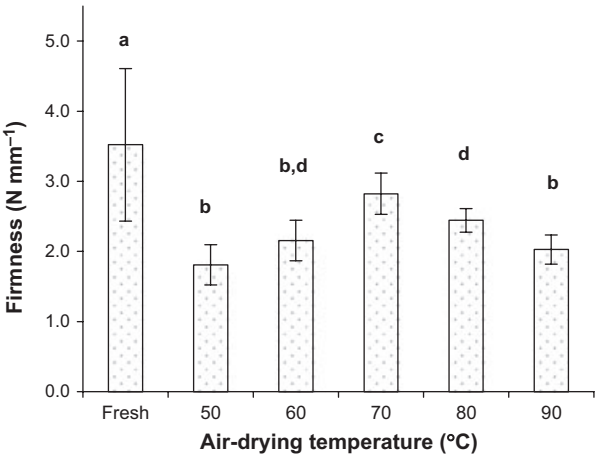

Figure 5 Effect of air-drying temperature on the firmness of fresh and dehydrated pepino fruit samples. Identical letters above the bars indicate no significant difference ($P < 0.05$).

Conclusions

In this study, the effect of drying temperature on quality of dehydrated pepino fruit was investigated. Drying temperature ranged from 50 to 90 °C. When comparing the fresh with the corresponding dehydrated pepino samples ($P < 0.05$), it was showed that the drying operation resulted in important reductions of proteins, fat and crude fibres. Changes in chromatic coordinates due to increasing drying temperature led to a noticeable modification of surface fruit colour as indicated through the ΔE parameter ($P < 0.05$). Non-enzymatic browning was more pronounced for temperatures higher than 50 °C ($P < 0.05$). Vitamin C content and TPC decreased as air-drying temperature increased for the whole range of temperatures under study ($P < 0.05$). Moreover, effects of drying times were observed at low temperature (50 °C) respect to high temperatures, where long process times led to a noticeable reduction of antioxidant activity. In addition, a fruit tissue firmness reduction was observed for all the treatments, especially at 50 and 90 °C ($P < 0.05$). In conclusion, the results of this work indicate that the reported quality profiles of pepino fruit can be used to optimise the dehydration process using the air-drying temperature as the control process variable in order to minimise detrimental changes in the original fruit characteristics.

Acknowledgement

The authors thank the Research Office of Universidad de La Serena, Chile, for the support provided through Project DIULS No. 220-2-06.

References

Acevedo, N.C., Briones, V., Buera, P. & Aguilera, J.M. (2008). Microstructure affects the rate of chemical, physical and color changes during storage of dried apple discs. *Journal of Food Engineering*, **85**, 222–231.

Ahumada, M. & Cantwell, M. (1996). Postharvest studies on pepino dulce *(Solanum muricatum* Ait.): maturity at harvest and storage behaviour. *Postharvest Biology and Technology*, **7**, 129–136.

AOAC. (1990). *Official Method of Analysis. Association of Official Analytical Chemists*, 15th ed. Washington. DC. USA: Association of Official Analytical Chemists.

Attanasio, G., Cianquanta, L. & Matteo, M.D. (2004). Effect of drying temperature on physico-chemical properties of dried and rehydrated chestnuts (*Castanea sativa*). *Food Chemistry*, **88**, 583–590.

Bahloul, N., Boudhrioua, N., Kouhila, M. & Kechaou, N. (2009). Effect of convective solar drying on colour, total phenols and radical scavenging activity of olive leaves (*Olea europaea* L.). *International Journal of Food Science and Technology*, **44**, 2561–2567.

Barakat, M.Z., El-Wahab, M.F.A. & El-Sadr, M.M. (1955). Action of N-bromosuccinimide on ascorbic acid. Biochemistry department, faculty of medicine, Abbassia, Cairo, Egypt. *Analytical Chemistry*, **27**, 536–540.

Barbosa-Canovas, G.V. & Vega-Mercado, H. (2000). *Deshidratación de Alimentos*. Spain: Editorial Acribia S.A. Zaragoza.

Barta, J. (2006). Fruit drying principles. In: *Handbook of Fruits and Fruits Processing* (edited by Y.H. Hui). Pp. 81–93. Iowa: Blackwell Publishing.

Carabasa-Giribet, M. & Ibarz-Ribas, A. (2000). Kinetics of colour development in aqueous glucose systems at high temperatures. *Journal of Food Engineering*, **44**, 181–189.

Cartron, E., Carbonneau, M.A., Fouret, G., Descomps, B. & Leger, C.L. (2001). Specific antioxidant activity of caffeoyl derivatives and another natural phenolic compounds: LDL protection against oxidation and decrease in the proinflammatory lisophosphatidylcholine production. *Journal of Natural Products*, **64**, 480–486.

Cernîşev, S. (2010). Effects of conventional and multistage drying processing on non-enzymatic browning in tomato. *Journal of Food Engineering*, **96**, 114–118.

Chan, E.W.C., Lim, Y.Y., Wong, S.K. *et al*. (2009). Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. *Food Chemistry*, **113**, 166–172.

Chen, X.D. (2008). Food drying fundamentals. In: *Drying Technologies in Food Processing* (edited by X.D. Chen & A.S. Mujumdar). Pp. 1–54. West Sussex: Wiley-Blackwell Publishing.

Chuah, A.M., Lee, Y-C., Yamaguchi, T., Takamura, H., Yin, L.J. & Matoba, T. (2008). Effect of cooking on the antioxidant properties of coloured peppers. *Food Chemistry*, **111**, 20–28.

Devahastin, S. & Niamnuy, C. (2010). Modelling quality changes of fruits and vegetables during drying: a review. *International Journal of Food Science and Technology*, **45**, 1755–1767.

Di Scala, K.C. & Crapiste, G.H. (2008). Drying kinetics and quality changes during drying of red pepper. *LWT – Food Science and Technology*, **41**, 789–795.

Díaz, N.L. (2006). Industrialización y aprovechamiento de productos y subproductos derivados de materias primas agropecuarias de la Región de Coquimbo. LOM ediciones Ltda.

Ergünes, G. & Tarhan, S. (2006). Color retention of red peppers by chemical pretreatments during greenhouse and open sun drying. *Journal of Food Engineering*, **76**, 446–452.

Fernandes, F., Rodrigues, S., Law, C.H. & Mujumdar, A. (2010). Drying of exotic tropical fruits: a comprehensive review. *Food and Bioprocess Technology*. DOI 10.1007/s11947-010-0323-7, in press.

Galletti, L., Berger, H., Drouilly, D. & Lizana, L.A. (2006). Atmósfera modificada en fruto de pepino dulce modified atmosphere in cachun fruits (Solanum muricatum Ait). IDESIA (Chile). Centro de Estudios Postcosecha (CEPOC), Facultad de Ciencias Agronómicas. *Universidad de Chile*, **24**, 35–40.

Garau, M.C., Simal, S., Roselló, C. & Femenia, A. (2007). Effect of air-drying temperature on physico-chemical properties of dietary fibre and antioxidant capacity of orange (Citrus aurantium v. Canoneta) by-products. *Food Chemistry*, **104**, 1014–1024.

Giovanelli, G. & Buratti, S. (2009). Comparison of polyphenolic composition and antioxidant activity of wild Italian blueberries and some cultivated varieties. *Food Chemistry*, **112**, 903–908.

Heredia, A., Heredia, C., Barrera, A. & Andrés, A. (2007). Drying of cherry tomato by a combination of different dehydration techniques. Comparison of kinetics and other related properties. *Journal of Food Engineering*, **80**, 111–118.

Huyskens-Keil, S., Prono-Widayat, H., Ludders, P. & Schreiner, M. (2006). Postharvest quality of pepino (Solanum muricatum Ait.) fruit in controlled atmosphere storage. *Journal of Food Engineering*, **77**, 628–634.

Kaya, A., Aydin, O. & Kolayli, S. (2009). Effect of different drying conditions on the vitamin C (ascorbic acid) content of Hayward kiwifruits (*Actinidia deliciosa* Planch). *Food and Bioproducts Processing*, **88**, 165–173. Doi:10.1016/j.fbp.2008.12.001.

Kim, S., Lee, K.W., Park, J., Lee, H.J. & Hwang, I.K. (2006). Effect of drying in antioxidant activity and changes of ascorbic acid and colour by different drying and storage in Korean red pepper (*Capsicum annuum* L.). *International Journal of Food Science and Technology*, **41**, 90–95.

Krokida, M.K., Maroulis, Z.B. & Saravacos, G.D. (2001). The effect of the method of drying on the colour of dehydrated products. *International Journal of Food Science and Technology*, **36**, 53–59.

Kuskoski, E.M., Asuero, A.G., Troncoso, A.M., Mancini-Filho, J. & Fett, R. (2005). Aplicación de diversos métodos químicos para determinar actividad antioxidante en pulpa de frutos. *Ciência e Tecnología de Alimentos*, **25**, 726–732.

Leite, J.B., Mancini, M.C. & Borges, S.V. (2007). Effect of drying temperature on the quality of dried bananas cv. prata and d'a′gua. *LWT-Food Science and Technology*, **40**, 319–323.

Locatelli, M., Gindro, R., Travaglia, F., Coïsson, J-D., Rinaldi, M. & Arlorio, M. (2009). Study of the DPPH_-scavenging activity: development of free software for the correct interpretation of data. *Food Chemistry*, **114**, 889–897.

López, J., Uribe, E., Vega-Gálvez, A. *et al*. (2009). Effect of air temperature on drying kinetics, vitamin c, antioxidant activity, total phenolic content, non-enzymatic browning and firmness of blueberries variety O′Neil. *Food and Bioprocess Technology*, **3**, 772–777.

López-Nicolas, M.J. & García-Carmona, F. (2010). Enzymatic and Nonenzymatic Degradation of Polyphenols. In: *Fruit and vegetables Phytochemicals* (edited by L. de la Rosa, E. Alvarez-Parrilla & G. Gónzalez-Aguilar). Pp. 101–103. Iowa: Wiley-Blackwell Publishing.

Luangmalawat, P., Prachayawarakorn, S., Nathakaranakule, A. & Soponronnarit, S. (2008). Effect of temperature on drying characteristics and quality of cooked rice. *LWT – Food Science and Technology*, **41**, 716–723.

Maestri, D.M., Nepote, V., Lamarque, A.L. & Zygadlo, J.A. (2006). Natural products as antioxidants. In: *Phytochemistry: Advances in Research* (edited by Imperato). Pp. 105–135. Kerala, India: Research Signpost.

Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M. & Lerici, C. (2001). Review of non-enzymatic browning and antioxidant capacity in processed foods. *Trends in Food Science and Technology*, **11**, 340–346.

Marfil, P.H.M., Santos, E.M. & Telis, V.R.N. (2008). Ascorbic acid degradation kinetics in tomatoes at different drying conditions. *LWT – Food Science and Technology*, **41**, 1642–1647.

Meydav, S. (1977). rowning determination in citrus products. *Journal of Agriculture and Food Chemistry*, **25**, 602–604.

Miranda, M., Maureira, H., Rodríguez, K. & Vega-Gálvez, A. (2009). Influence of temperature on the drying kinetics, physicochemical properties, and antioxidant capacity of Aloe Vera (Aloe Barbadensis Miller) gel. *Journal of Food Engineering*, **91**, 297–304.

Miranda, M., Vega-Gálvez, A., García, P. *et al*. (2010). Effect of Temperature on Structural Properties of *Aloe vera* (*Aloe barbadensis* Miller) Gel and Weibull distribution for modelling drying process. *Food and Bioproducts Processing*, **88**, 138–144.

Mujumdar, A. & Law, C.L. (2010). Drying technology: trends and applications in postharvest Processing. *Food and Bioprocess Technology*. **3**, 843–852. DOI: 10.1007/s11947-010-0353-1.

Nuez, F. & Ruiz, J. (1996) *El pepino dulce y su cultivo*. Roma: Estudio de la FAO producción y protección vegetal.

Perera, C.O. (2005). Selected quality attributes of dried foods. *Drying Technology*, **23**, 717–730.

Podsedek, A. (2007). Natural antioxidant and antioxidant capacity of Brassica vegetables. A review. *LWT: Food Science and Technology*, **40**, 1–11.

Prathapan, A., Lukhman, M., Arumughan, C., Sundaresan, P. & Raghu, K. (2009). Effect of heat treatment on curcuminoid, colour value and total polyphenols of fresh turmeric rhizome. *International Journal of Food Science and Technology*, **44**, 1438–1444.

Prohens, J., Miro, R., Rodriguez–Burruezo, A., Chiva, S., Verdu, G. & Nuez, F. (2004). Temperature, electrolyte leakage, ascorbic acid content and sunscald in two cultivars of pepino, *Solanum muricatum*. *Journal of Horticultural Science & Biotechnology*, **79**, 375–379.

Qu, W., Pan, Z. & Ma, H. (2010). Extraction modeling and activities of antioxidants from pomegranate marc. *Journal of Food Engineering*, **99**, 16–23.

Que, F., Mao, L., Fang, X. & Wu, T. (2008). Comparison of hot air-drying and freeze-drying on the physicochemical properties and antioxidant activities pumpkin (*Cucurbita moschta* Duch) flours. *International Journal of Food Science and Technology*, **43**, 1195–1201.

Sablani, S.S. (2006). Drying of fruits and vegetables: retention of nutritional/functional quality. *Drying Technology*, **24**, 123–135.

Seifried, H.E. (2007). Oxidative stress and antioxidants: a link to disease and prevention? *Journal of Nutritional Biochemistry*, **18**, 168–171.

Sigge, G.O., Hansmann, C.F. & Jourbert, E. (2001). Effect of storage conditions, packaging material and metabisulfite treatment on the color of dehydrated green bell peppers (Capsicum Annuum L.). *Journal of Food Quality*, **24**, 205–218.

Sun, J., Yao, J., Huang, S., Long, X., Wang, J. & García-García, E. (2009). Antioxidant activity of polyphenol and anthocyanin extracts from fruits of *Kadsura coccinea* (Lem.) A.C. Smith. *Food Chemistry*, **117**, 276–281.

Toor, R.K. & Savage, G.P. (2006). Effect of semi-drying on the antioxidant components of tomatoes. *Food Chemistry*, **94**, 90–97.

Turkmen, N., Sari, F. & Velioglu, Y.S. (2005). The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. *Food Chemistry*, **93**, 713–718.

Uribe, E., Vega-Gálvez, A., Di Scala, K., Oyanadel, R., Saavedra, J. & Miranda, M. (2009). Characteristics of convective drying of pepino fruit (*Solanum muricatum* Ait.): application of weibull distribution. *Food Bioprocess Technology*, DOI: 10.1007/s11947-009-0230-y, in press.

Vega-Gálvez, A., Lemus-Mondaca, R., Bilbao-Sáinz, C., Fito, P. & Andrés, A. (2008). Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. Lamuyo). *Journal of Food Engineering*, **85**, 42–50.

Vega-Gálvez, A., Di Scala, K., Rodríguez, K. *et al*. (2009). Effect of air-drying temperature on physico-chemical properties, antioxidant capacity, colour and total phenolic content of red pepper (*Capsicum annum, L. var*. Hungarian). *Food Chemistry*, **117**, 647–653.

Wang, L.S. & Stoner, G.D. (2008). Anthocyanins and their role in cancer prevention. *Cancer Letters*, **269**, 281–290.