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Impact of air-drying temperature on nutritional properties, total phenolic content and antioxidant capacity of quinoa seeds (*Chenopodium quinoa* Willd.)

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ABSTRACT

Quinoa has gained an increasing interest in recent years due to its nutritional value (rich in protein, fat, dietary fibre, ash, carbohydrates and minerals). Furthermore, it is an excellent source of natural antioxidants such as vitamin E and other phytochemicals. Dehydration of quinoa between 40 and 80 °C was performed in order to evaluate the effect of air-drying temperature on these quality attributes. When comparing the fresh with the corresponding dehydrated quinoa samples, it was shown that the drying operation led to reductions of 10% in proteins, 12% in fat and 27% in both fibres and ashes. In fresh quinoa, potassium and copper were found to be the most and least abundant minerals, respectively. Sucrose was the predominant sugar, followed by fructose and glucose. Overall antioxidant activity was affected by drying temperatures. Thermal degradation, especially at 60, 70 and 80 °C, resulted in a notable reduction in TPC. However, vitamin E showed an important increase at 70 and 80 °C. The antioxidant capacity presented similar values at 40, 50 and 80 °C due to temperature/drying time equivalent processes.

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a native food plant of the Andean region. The seed is resistant to drought and frost and is frequently cultivated on poor soils (Vilche et al., 2003). The Incas appreciated their high nutritional value, and the ease in milling these crops made it possible for the rural populations to take advantage of their nutritional value and the exceptional balance between oil, protein and fats (Repo-Carrasco et al., 2003; Bhargava et al., 2006; Comai et al., 2007). Nowadays, Peru, Bolivia, Chile, Ecuador, Colombia and Argentina have expanded the production of this pseudocereal focusing on great technological and commercial interest not only for human nutrition but also due to the releases of by-products that offer good nutritional alternatives for animals feeding as well as applications in pharmaceutical industry (Repo-Carrasco et al., 2003; Tolaba et al., 2004; Bhargava et al., 2006; Gely and Santalla, 2007; Brady et al., 2007). Quinoa has a protein content that is higher, and an amino acid composition that is better balanced than the major cereals, close to the ideal recommended by the FAO (Oshodi et al., 1999; Comai et al., 2007). In addition, it has a wide range of vitamins and microelements (Konishi et al., 2004; Bhargava et al., 2006). Minerals in the diet are required for metabolic reactions, transmission of nerve impulses, rigid bone formation and regulation of water and salt balance among others (Dini et al., 2008). The seeds are excellent examples of functional food defined as lowering the risk of various diseases and/or exerting health-promoting effects (Paśko et al., 2009). Its antioxidant activity is associated to its content of vitamin E and phenolic compounds (Vilche et al., 2003; Choi et al., 2006; Paśko et al., 2008). Tocopherols (vitamin E) are a major lipid soluble antioxidant present in the polyunsaturated fatty acid enriched membranes of chloroplasts; they interact with the polyunsaturated acyl groups of lipids, stabilize membranes, and scavenge and quench various reactive oxygen species and lipid soluble by-products of oxidative stress (Sattler et al., 2004; Maestri et al., 2006).

Increasing appreciation of the nutritional and functional properties of quinoa is likely to encourage the investigation of effects of processing on such product attributes in order to minimise quality degradation. Dehydration has become a widely used food preservation process allowing the extension of the shell-life of most agro-food products. Its main objective is the removal of water to the level at which microbial spoilage and deterioration reactions are minimised. Nevertheless, it is well known that during hot air-drying, food undergoes several physical, chemical, organoleptic and

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nutritional changes that can cause loss quality of the final product (Vega-Gálvez et al., 2009a). Thus, in order to control these modifications, it is fundamental to study the influence of the main operative variable, which is the process temperature, on these properties. Therefore, the aim of this work was to evaluate the effect of air-drying temperature on nutritional properties as well as antioxidant activity related to vitamin E and total phenolic content that occurred during convective drying of quinoa.

2. Materials and methods

2.1. Sample preparation and drying process

The seeds of quinoa (*Chenopodium quinoa* Willd.) were grown and harvested in Elqui Valley, city of La Serena, Chile. Before drying, fresh quinoa were subjected to visual inspection to discard contaminant particles or impurities. In order to remove the saponins, which are the main antinutritional factors present in the seed coat of quinoa, the samples were washed with distilled water at 60 °C (with agitation) during one hour with a sample to water ratio of 1:10 ($w\,w^{-1}$) (Bhargava et al., 2006; Vega-Gálvez et al., in press).

The drying was carried out at 40, 50, 60, 70 and 80 °C using a convective dryer built in the Department of Food Engineering of Universidad de La Serena, with a constant air flow rate of $2.0 \pm 0.2\,m\,s^{-1}$ (Vega-Gálvez et al., 2009a, in press). The mass sample and the charge load were 2.5 ± 0.2 g and $1.4 \pm 0.1\,kg\,m^{-2}$, respectively. The samples were dried until they reached constant weight (equilibrium condition) presenting minimum and maximum drying times of 150 min and 420 min at 80 °C and 40 °C, respectively (Vega-Gálvez et al., in press). All drying experiments were performed in triplicate.

2.2. Physico-chemical analysis

The moisture content was determined by AOAC method no 934.06 (AOAC, 1990) employing a vacuum oven (Gallenkamp, OVL570, Leicester, UK) and an analytical balance with an accuracy of ±0.0001 g (CHYO, Jex120, Kyoto, Japan). 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 analyzed 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 available carbohydrate was estimated by difference. All methodologies followed the recommendations of the Association of Official Analytical Chemists (AOAC, 1990). All measurements were done in triplicate.

2.3. Determination of sugars

The carbohydrates, namely fructose, glucose and sucrose were quantified by high performance thin-layer chromatography (HPTLC) according to the methodology suggested by Patzsch et al. (1988) and Aranda et al. (2005). All the analyses were made in triplicate. Sugar content was expressed as $g\,100\,g^{-1}$ dry matter.

2.4. Determination of minerals

Mineral elements (Na, K, Ca, Mg, Cu, Mn, Zn, and Fe) were measured by an atomic absorption spectrophotometer (AAS, Shimadzu Instruments, Inc., SpectrAA-220, Kyoto, Japan) after the digestion of an H_2SO_4, HNO_3 and $HClO_4$ mixture. The P content was estimated using a phospho-vanadium-molibdenum complex at 466 nm (Shimadzu Instruments, Inc., Spectrophotometer UV-120-02, Kyoto, Japan) as described by previous works (García-Hernandez et al., 2006; Femenia et al., 1999). All determinations were done in triplicate. The minerals were expressed as $g\,100\,g^{-1}$ dry matter.

2.5. Determination of vitamin E

Samples were extracted with methanol-BHT ($1\,mg\,mL^{-1}$) solution as described by Zeng et al. (1999). The separation was carried out using a Symmetry column (150×4.6 mm, 5 μm) from Water (Milford, MA, USA) with methanol:acetonitrile ($1{:}1\,v\,v^{-1}$) as mobile phase with a flow rate of $1.2\,mL\,min^{-1}$. Detection was performed by fluorescence using 295 nm and 325 nm as excitation and emission wavelengths, respectively. All measurements were done in triplicate. The vitamin E content was expressed in $mg\,100\,g^{-1}$ dry matter.

2.6. Determination of total phenolic content

Total phenolic content (TPC) were determined colorimetrically using 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 ultra-pure water were added and the formed precipitate was removed by centrifugation during 5 min at $4000 \times g$. Finally, the absorbance was measured in a spectrophotometer (Spectronic® 20 GenesysTM131, Illinois, USA) at 725 nm and compared to a galic 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.

2.7. Determination of DPPH radical scavenging 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™, Illinois, 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 Eq. (1):

$$\%TAA = \left(1 - \left(\frac{Abs_{sample}}{Abs_{control}}\right)\right) \times 100 \quad (1)$$

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 ($\mu g\,mL^{-1}$ sample).

2.8. Statistical analysis

The effect of air-drying temperature on quality parameters was estimated using Statgraphics® Plus 5 (Statistical Graphics Corp., Herndon, VA, USA). One-way ANOVA with five levels, three replicates was performed. Differences among the media were analyzed

Table 1
Chemical characterization of fresh and dehydrated quinoa samples, g 100 g^{-1} dry matter.

Parameters	Fresh	40 (°C)	50 (°C)	60 (°C)	70 (°C)	80 (°C)
Moisture	13.42 ± 0.30^{a}	10.67 ± 0.60^{b,c}	11.05 ± 0.20^{c}	9.80 ± 0.41^{b}	5.74 ± 0.90^{d}	6.31 ± 0.04^{d}
Crude protein (N × 6.25)	12.46 ± 0.22^{a,c}	11.17 ± 0.67^{b}	11.82 ± 0.37^{a,b,c}	12.59 ± 0.81^{c}	11.54 ± 0.54^{a,b}	11.20 ± 0.18^{b}
Fat	8.47 ± 0.96^{a}	7.43 ± 0.51^{b}	7.58 ± 0.25^{a,b}	7.72 ± 0.51^{a,b}	7.38 ± 0.33^{b}	7.48 ± 0.24^{b}
Crude fibre	1.92 ± 0.15^{a}	1.70 ± 0.09^{a}	1.61 ± 0.18^{a,b}	1.63 ± 0.15^{a,b}	1.37 ± 0.24^{b}	1.39 ± 0.20^{a,b}
Ash	3.71 ± 0.08^{a}	2.63 ± 0.04^{b}	2.43 ± 0.15^{b}	2.60 ± 0.43^{b}	2.54 ± 0.02^{b}	2.69 ± 0.10^{b}
Available carbohydrates (by difference)	60.01 ± 0.99^{a}	66.40 ± 0.98^{b,c}	65.50 ± 0.33^{b}	71.43 ± 1.35^{b}	70.93 ± 0.87^{c}	77.23 ± 0.27^{c}

Different letters in the same column indicate that the values are significantly different ($p < 0.05$).

using the least significant difference (LSD) test with a significance level of $\alpha = 0.05$ and a confidence interval of 95% ($p < 0.05$). In addition, the multiple range test (MRT) included in the statistical program was used to demonstrate the existence of homogeneous groups within each of the parameters.

3. Results and discussion

3.1. Effect on physico-chemical properties

Table 1 shows the mean values and standard deviations of the proximate analysis of quinoa seeds including moisture, crude protein, fat, crude fibre, ash and available carbohydrates of both fresh and dried samples. Significant differences were found between the mentioned properties and temperature ($p < 0.05$). The moisture, crude protein, fat and ash contents of fresh quinoa are similar to those reported by other authors (Oshodi et al., 1999; Ogungbenle, 2003; Repo-Carrasco et al., 2003; Dini et al., 2005; Bhargava et al., 2006). The fibre content is comparable to the values reported by previous studies (Dini et al., 2008; Bhargava et al., 2006). It has been discovered that high values of fibre can improve digestibility and absorption processes (Ogungbenle, 2003). Carbohydrates content of fresh quinoa is higher than the correspondent value reported by Koziol (1992).

When analyzing Table 1, the chemical composition of the dehydrated quinoa samples (except for the moisture content) from the lowest (40 °C) to the highest process temperatures (80 °C) presented comparable values for each chemical compounds. However, when comparing the fresh with the corresponding dehydrated quinoa samples, it was shown that the drying operation leads to reductions of 10% in proteins, 12% in fat and 27% in both fibres and ashes. The loss of protein could be due to denaturation or changes in solubility during drying. Moreover, another possible cause in this reduction is the release of amino acids from the proteins after denaturation which could react with other chemicals compounds such as sugars to produce melanoidines via the Maillard reaction (Lee and Shibamoto, 2002; Perera, 2005; Miranda et al., 2009; Borompichaichartkul 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; Stenberg et al., 2005). In addition, the reduce of ash content may have ocurred as a result of the leaching of soluble inorganic compounds during saponin removal with water (Ruales and Nair, 1993; Bhargava et al., 2006)

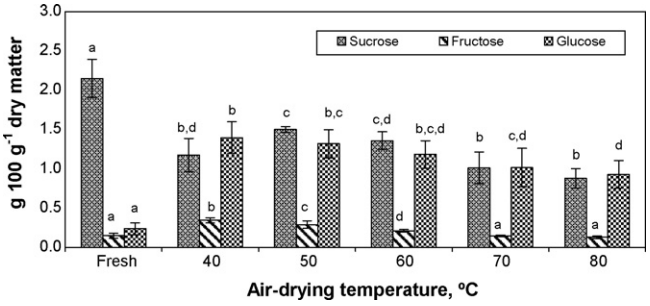

Fig. 1. Effect of air-drying temperature on free soluble sugars of fresh and dehydrated quinoa samples. Identical letters above the bars indicate no significant difference ($p < 0.05$).

3.2. Effects on free soluble sugars

Sugars are responsible for the sweetness of foods. Individual sugars possess different relative sweetness scores; fructose has been reported to be the sweetest sugar, followed by sucrose and glucose (Dini et al., 2005). Furthermore, the presence of sugars in cereal seeds indicate that necessary materials needed to release energy during tissue respiration are readily available which guarantee readiness for energy supply in aid of seed germination (Alabi and Alausa, 2006). Fig. 1 shows the main free soluble sugars contents for both fresh and dehydrated quinoa seeds. Sucrose (2.15 ± 0.24 g 100 g^{-1} d.m.) was the predominant sugar identified for the fresh quinoa. The reducing sugars presented an initial value of 0.15 ± 0.03 g 100 g^{-1} d.m. and 0.24 ± 0.07 g 100 g^{-1} d.m., for fructose and glucose, respectively. The content of the three sugars were lower than those reported by Repo-Carrasco et al. (2003) but higher compared to the work of Ogungbenle (2003). The above mentioned author reported that D-Xylose was the richest sugar in quinoa but low in glucose and fructose and Oshodi et al. (1999) observed that maltose was the predominant sugar. These differences could be related to several factors, like specific varieties, growth, storage conditions and the period after harvesting (Oshodi et al., 1999).

Table 2
Minerals compositions of fresh and dehydrated quinoa samples, mg 100 g^{-1} dry matter.

Mineral	Fresh	40 (°C)	50 (°C)	60 (°C)	70 (°C)	80 (°C)
Phosphorus	468.87 ± 4.50^{a,b}	481.13 ± 21.88^{b}	452.89 ± 7.91^{a,b}	462.25 ± 13.73^{a,b}	447.73 ± 13.09^{a,b}	441.98 ± 39.57^{a}
Copper	0.20 ± 0.04^{a}	0.41 ± 0.01^{b}	0.24 ± 0.01^{c}	0.23 ± 0.02^{a,c}	0.26 ± 0.03^{c}	0.30 ± 0.01^{d}
Manganese	2.29 ± 0.14^{a}	2.04 ± 0.03^{b}	1.93 ± 0.03^{b,c}	1.97 ± 0.08^{b,c}	1.91 ± 0.08^{b,c}	1.79 ± 0.18^{c}
Iron	13.96 ± 1.03^{a}	7.67 ± 0.94^{b}	5.79 ± 0.02^{c}	5.63 ± 0.23^{c}	5.94 ± 0.79^{c}	5.75 ± 0.48^{c}
Zinc	2.77 ± 0.08^{a}	2.97 ± 1.00^{a}	2.81 ± 0.05^{a}	2.85 ± 0.21^{a}	2.87 ± 0.19^{a}	2.52 ± 0.04^{b}
Calcium	56.51 ± 1.67^{a}	106.50 ± 1.35^{b}	110.19 ± 2.84^{c,b}	113.15 ± 1.50^{d}	108.04 ± 0.40^{b,c}	108.25 ± 0.31^{b,c}
Magnesium	176.02 ± 4.18^{a,b}	184.95 ± 4.18^{b}	178.10 ± 2.84^{c,b}	180.28 ± 6.55^{b}	180.65 ± 7.70^{b}	168.49 ± 1.20^{a}
Sodium	26.55 ± 1.30^{a,c}	19.31 ± 0.52^{b}	24.04 ± 0.46^{a}	27.92 ± 2.30^{c}	35.73 ± 2.83^{d}	53.61 ± 1.92^{e}
Potassium	1192.95 ± 17.60^{a}	672.50 ± 4.01^{b}	630.63 ± 4.46^{c,d}	639.39 ± 2.32^{c}	641.05 ± 10.63^{c}	617.83 ± 2.20^{d}

Different letters in the same column indicate that the values are significantly different ($p < 0.05$).

As observed in Fig. 1, all drying temperatures provoked a decrease in the sucrose content probably due to hydrolysis of the disaccharide (Colin-Henrion et al., 2009; Borompichaichartkul et al., 2009). The major loss of this sugar (56%) was presented at high drying temperature (i.e. 80 °C).

3.3. Determination of minerals

Table 2 shows the composition of nine essential minerals, i.e., phosphorus, copper, manganese, iron, zinc, calcium, magnesium, sodium and potassium of fresh and dehydrated quinoa at different drying temperatures. In fresh quinoa, potassium was found to be the most abundant mineral with a value of 1192.95 ± 17.60 mg 100 g^{-1} d.m., while copper was the least abundant with a value of 0.20 ± 0.04 mg 100 g^{-1} d.m. This was in close agreement with the observation made by other publications (Koziol, 1992; Ogungbenle, 2003; Konishi et al., 2004; Bhargava et al., 2006). It has been reported that potassium is essential as an activator for enzymes involved in the synthesis of certain peptide bonds (Alabi and Alausa, 2006). In addition, quinoa has a higher content of calcium, magnesium, iron, copper, and zinc than other cereals (Schlick and Bubenheim, 1996; Repo-Carrasco et al., 2003). Furthermore, the value of calcium in quinoa (56.51 mg 100 g^{-1} d.m.) is adequate for infant development of bones and teeth (Ogungbenle, 2003). Manganese plays an important role in respiration and nitrogen metabolism, while copper acts as a component of phenolases, laccase and ascorbic acid oxidase (Alabi and Alausa, 2006). Levels of zinc found in the different tissues of the plant are known to be essential for the function and/or structure of several enzymes including peptidases, transphosphorylase, etc. It has also been found to be an essential component of both DNA and RNA polymerases. In addition, zinc is also known for its anti-viral, anti-bacterial, anti-fungal and anti-cancer properties (Brisibe et al., 2009).

Some differences were found when comparing the quinoa minerals contents of the present investigation with the mineral composition reported by other authors for the same cereal (Oshodi et al., 1999; Ogungbenle, 2003; Repo-Carrasco et al., 2003). For example, the values for potassium, phosphorus and iron of fresh quinoa were higher but those of sodium, copper, zinc; calcium and magnesium were lower than the values found by Ogungbenle (2003). These differences may be linked to the fact that the quinoa samples were from different cultivation areas. Thus, the mineral content may vary depending on several factors such as ripeness, variety, soil type, the use of fertilizers, intensity and exposure time to sunlight, temperature, rain, etc. (Zielisnki and Koslowska, 2000; Miranda et al., 2009).

The calcium content of dehydrated samples increased significantly when compared to the raw material, from 56.51 ± 1.67 to 108.25 ± 0.31 mg 100 g^{-1} d.m. at 80 °C. Moreover, phosphorus, zinc and magnesium presented slight losses (<10%) while potassium and iron showed an important decrease of 48% and 58%, respectively. Reduction in minerals contents could be due to interaction of saponins with minerals before processing (Güçlü-Üstündağ and Mazza, 2007) or diffusion of these micronutrients into intercellular spaces especially at high temperatures (Ruales and Nair, 1993; Bhargava et al., 2006).

3.4. Antioxidant activity

Food antioxidant activity depends on many factors such as the lipid composition, antioxidant concentration, temperature, oxygen pressure, and the presence of other antioxidants and many common food components, e.g. proteins and water. Antioxidants can inhibit or retard oxidation in two ways: either by scavenging free radicals, in which case the compound is described as a primary antioxidant, or by a mechanism that does not involve direct scavenging of free radicals, in which case the compound is a secondary antioxidant. Primary antioxidants include phenolic compounds such as vitamin E (α-tocopherol). Vitamin E is a fat-soluble and loss of this food component by radical-catalysed reactions may often accompany lipid oxidation (Maestri et al., 2006). Vitamin E acts as an antioxidant at the cell membrane level, protecting the fatty acids of the membranes against damage caused by free radicals (Repo-Carrasco et al., 2003).

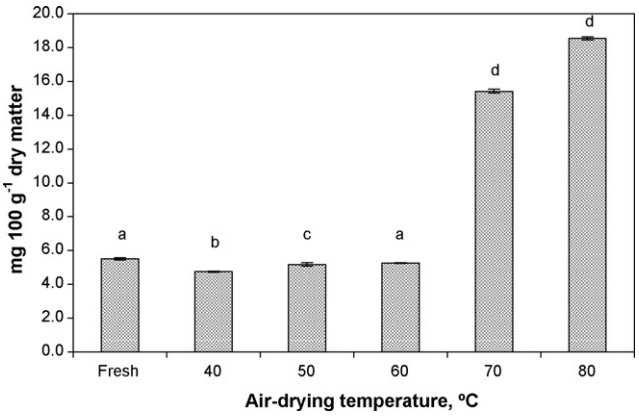

Fig. 2. Effect of air-drying temperature on vitamin E content of fresh and dehydrated quinoa samples. Identical letters above the bars indicate no significant difference ($p < 0.05$).

Fig. 2 shows the effect of drying temperature on vitamin E for the fresh and dehydrated samples ($p < 0.05$). The initial content of vitamin E was 5.51 ± 0.07 mg 100 g^{-1} d.m. Similar contents were reported by Koziol (1992). It can be observed that from 40 to 60 °C of process temperature, the vitamin content remained constant but an important increase at high temperatures (i.e. 70 and 80 °C) was informed. Although some authors have reported that tocopherols are very stable with respect to heat, the variation in temperature may change the mechanism of action of some antioxidants, and as a result the order of their effectiveness (Maestri et al., 2006; Vadivambal and Jayas, 2007). The enhancement at high temperatures could be due to tocopherols (vitamin E) scavenge lipid peroxy radicals and yield a tocopheroxyl radical that can be recycled back to the corresponding tocopherol by reacting with ascorbate or other antioxidants through different chemical reactions (Sattler et al., 2004). In addition, depending on the food matrix a significant amount of vitamin E linked to proteins or phospholipids could be released by the heat treatment breakdown. Thus, a higher content of this vitamin can be obtained compared to the non-processed cereal. This increasing availability due to heat treatments has been reported by other authors in different cereals (Casal et al., 2006).

Another group of phenolic substances with antioxidant properties is phenolic acids. The antioxidant activity of these compounds is mainly due to their redox properties, which allow them to act as reducing agents, hydrogen donators, and singlet oxygen quenchers. Among them, gallic acid, a natural product arising from tannin hydrolysis, has attracted considerable interest (Maestri et al., 2006). The total phenolic content (TPC) was determined according the Folin-Ciocalteu method with Gallic acid as a standard compound ($r^2 = 0.99$, $y = 0.0047x + 0.0635$) (data not shown). TPC ranged from 28.41 ± 2.90 to 1.59 ± 0.53 mg GA 100 g^{-1} d.m. The initial content is comparable to the results reported by Paśko et al. (2008). These authors reported that the amount of gallic acid in the seeds of the pseudocereals was many times higher than in white corn seeds or in brown rice seeds (Paśko et al., 2008). The influence of temperature on TPC for fresh and dehydrated quinoa is shown in Fig. 3 ($p < 0.05$). It can be observed that an increase in drying tempera-

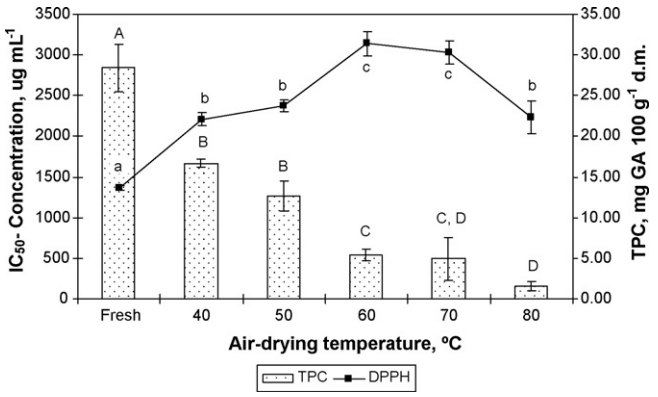

Fig. 3. Effect of air-drying temperature on total phenolic content (TPC) and DPPH free radical scavenging activity (IC_{50}) of fresh and dehydrated quinoa samples. Identical letters above the bars indicate no significant difference ($p < 0.05$).

ture had an important effect on the total phenolic content, leading to a notable reduction in these components, especially at high temperatures (e.g. 60, 70 and 80 °C). Losses of TPC due to thermal degradation have been also reported by other authors (Chan et al., 2009). In addition, decreases 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 (Martín-Cabrejas et al., 2009; Qu et al., 2010).

Fig. 3 also shows the radical scavenging activity based on air-drying temperature ($p < 0.05$). When comparing the dehydrated samples, the higher antioxidant capacity was observed at 40, 50 and 80 °C rather than at 60 and 70 °C. Although some authors have reported that long drying times associated to low process temperature may promote a decrease of antioxidant capacity, in this case study, was not evidenced (Garau et al., 2007). Furthermore, the observed profile of DPPH could be related to generation and accumulation of different antioxidant compounds having a varying degree of antioxidant activity developing antagonistic or synergistic effects with themselves or with the other constituents of quinoa extracts (Zielisnki and Koslowska, 2000). Some authors reported a correlation between the TPC and IC_{50} during food dehydration (Abdalbasit et al., 2009). However, in this study the correlation coefficient between TPC and DPPH scavenging activity ($r^2 = 0.638$, $y = -51.995x + 2996.7$) was found to be weak, indicating that perhaps other phenolic or non-phenolic compounds might be also contributors to the antioxidant activity (Zielisnki and Koslowska, 2000; Nsimba et al., 2008).

Processing methods are known to have variable effects on TPC and antioxidant activity of food samples. Effects include little or no change, significant losses, or enhancement in antioxidant properties. Food processing can improve the properties of naturally occurring antioxidants or induce the formation of new compounds with antioxidant capacity, so that the overall antioxidant activity increases or remains unchanged (Chan et al., 2009). The relationship between TPC and antioxidant activity of foods during dehydration is still a complex issue due to several factors, such as drying method, type of extraction solvent, antioxidant assays, nature of phytochemicals and interactions of multiple antioxidant reactions (Vega-Gálvez et al., 2009a).

4. Conclusions

The effect of air-drying temperature on physico-chemical properties and antioxidant activity due to total phenolic content and vitamin E of quinoa during hot air-drying between 40 and 80 °C was investigated. When analyzing the chemical composition of the dehydrated quinoa (except for the moisture content) at the lowest and highest temperatures (at 40 and 80 °C) the dried quinoa had similar composition content. On the other hand, the changes observed by comparing fresh with the corresponding dehydrated products showed that the drying operation induces reductions of 10% in proteins, 12% in fat and 27% in both fibres and ashes, especially at high temperatures. Sucrose (2.15 ± 0.24 g 100 g^{-1} d.m.) was the predominant sugar identified for the fresh quinoa. The reducing sugars presented an initial value of 0.15 ± 0.03 g 100 g^{-1} d.m. and 0.24 ± 0.07 g 100 g^{-1} d.m., for fructose and glucose, respectively. The major loss of sucrose (56%) was observed at high temperature (i.e. 80 °C) probably due to chemical hydrolysis of the disaccharide. In fresh quinoa, potassium was found to be the most abundant mineral with a value of 1192.95 ± 17.60 mg 100 g^{-1} d.m., while copper was the least abundant with the value 0.20 ± 0.04 mg 100 g^{-1} d.m. The calcium content of dehydrated samples increased significantly when compared to the raw material, while potassium and iron presented an important decrease with temperature, especially at 80 °C. When analyzing antioxidant capacity from the vitamin E point of view, the vitamin content remained constant from fresh to 60 °C but a notorious increase at high temperatures (i.e. 70 and 80 °C) was informed, given an important add-value to the cereal. Furthermore, an increase in drying temperature leads to a reduction in the TPC content. When comparing the dehydrated samples, the higher antioxidant capacity was observed at 40, 50 and 80 °C rather than at 60 and 70 °C. A weak correlation was found between TPC and DPPH ($r^2 = 0.6383$). Generation and accumulation of these antioxidant compounds having a varying degree of antioxidant activity could also develop antagonistic or synergistic effects with themselves or with the other constituents of samples. These complex chemical interactions that influence the antioxidant capacity of quinoa during drying are still under investigation.

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References

Abdalbasit, A.M., Ramlah, M.I., Maznah, I., Norsharina, I., 2009. Antioxidant activity and phenolic content of phenolic rich fractions obtained from black cumin (*Nigella sativa*) seedcake. Food Chem. 116, 306–312.

Alabi, D.A., Alausa, A.A., 2006. Evaluation of the mineral nutrients and organic food contents of the seeds of *Lablab purpureus*, *Leucaena leucocephala* and *Mucuna utilis* for domestic consumption and industrial utilization. World J. Agric. Sci. 2, 115–118.

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

Aranda, M., Vega, M., Villegas, F., 2005. Routine method for quantification of starch by planar chromatography (HPTLC). J. Planar Chromatogr. 18, 285–289.

Bhargava, A., Shukla, S., Ohri, D., 2006. *Chenopodium quinoa*—an Indian perspective. Ind. Crop. Prod. 23, 73–87.

Borompichaichartkul, C., Luengsode, K., Chinprahast, N., Devahastin, S., 2009. Improving quality of macadamia nut (*Macadamia integrifolia*) through the use of hybrid drying process. J. Food Eng. 93, 348–353.

Brady, C.-T., Rosen, R., Sang, S., Karwe, V., 2007. Effects of processing on the nutraceutical profile of quinoa. Food Chem. 100, 1209–1216.

Brisibe, E.A., Umoren, U.E., Brisibe, F., Magalhães, P.M., Ferreira, J.F.S., Luthria, D., Wu, X., Prior, R.L., 2009. Nutritional characterisation and antioxidant capacity of different tissues of *Artemisia annua* L. Food Chem. 115, 1240–1246.

Casal, S., Amaral, J., Oliveira, B., 2006. Effects of food thermal processing on vitamin E contents. In: Braunstein, M. (Ed.), Vitamin E: New Research. Nova Science Publishers, Inc., pp. 39–67.

Chan, E.W.C., Lim, Y.Y., Wong, S.K., Lim, K.K., Tan, S.P., Lianto, F.S., Yong, M.Y., 2009. Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. Food Chem. 113, 166–172.

Choi, Y., Lee, S.M., Chun, J., Lee, H.B., Lee, J., 2006. Influence of heat treatment on the antioxidant activities and polyphenolic compounds of Shiitake (*Lentinus edodes*) mushroom. Food Chem. 99, 381–387.

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 Chem. 111, 20–28.

Colin-Henrion, M., Mehinagic, E., Renard, C., Richomme, P., Jourjon, F., 2009. From apple to applesauce: processing effects on dietary fibres and cell wall polysaccharides. Food Chem. 117, 254–260.

Comai, S., Bertazzo, A., Bailoni, L., Zancato, M., Coata, C.V.L., Allegri, G., 2007. The content of proteic and nonproteic (free and protein-bound) tryptophan in quinoa and cereal flours. Food Chem. 100, 1350–1355.

Dini, I., Tenore, G.C., Dini, A., 2008. Chemical composition, nutritional value and antioxidant properties of *Allium caepa* L. Var. *Troperana* (red onion) seeds. Food Chem. 107, 613–621.

Femenia, A., Sánchez, E.S., Simal, S., Roselló, C., 1999. Effects of drying pretreatments on the cell wall composition of grape tissues. J. Agric. Food Chem. 46, 271–276.

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

García-Hernandez, J.L., Valdez-Cepeda, R.D., Murillo-Amador, B., Beltrán-Morales, F.A., Ruiz-Espinoza, F.H., Orona-Castillo, I., Flores-Hernandez, A., Troyo-Diéguez, E., 2006. Preliminary compositional nutrient diagnosis norms in *Aloe vera* L. Grown on calcareous soil in an arid environment. Environ. Exp. Bot. 58, 244–252.

Gely, M.C., Santalla, E., 2007. Moisture diffusivity in quinoa (*Chenopodium quinoa* Willd.) seeds: effect of air temperature and initial moisture content of seeds. J. Food Eng. 78, 1029–1033.

Güçlü-Üstündağ, O., Mazza, G., 2007. Saponins: properties, applications and processing. Crit. Rev. Food Sci. Nutr. 47, 231–258.

Konishi, Y., Hirano, S., Tsuboi, H., Wada, M., 2004. Distribution of minerals in Quinoa (*Chenopodium quinoa* Willd.) Seeds. Biosci. Biotechnol. Biochem. 68, 231–234.

Koziol, M.J., 1992. Chemical composition and nutritional evaluation of quinoa (*Chenopodium quinoa* Willd.). J. Food Comp. Anal. 5, 35–68.

Lee, K.-G., Shibamoto, T., 2002. Toxicology and antioxidant activities of nonenzymatic browning reaction products: review. Food Rev. Int. 18 (2), 151–175.

Maestri, D.M., Nepote, V., Lamarque, A.L., Zygadlo, J.A., 2006. Natural products as antioxidants. In: Filippo Imperato (Ed.), Phytochemistry: Advances in Research. Research Signpost, pp. 105–135.

Martín-Cabrejas, M.A., Aguilera, Y., Pedrosa, M., Cuadrado, C., Hernández, T., Díaz, S., Esteban, R., 2009. The impact of dehydration process on antinutrients and protein digestibility of some legume flours. Food Chem. 114, 1063–1068.

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

Nsimba, R.Y., Kikuzaki, H., Konishi, Y., 2008. Antioxidant activity of various extracts fractions of *Chenopodium quinoa* and *Amaranthus* spp. seeds. Food Chem. 106, 760–766.

Ogungbenle, H.N., 2003. Nutritional evaluation and functional properties of quinoa (*Chenopodium quinoa*) flour. Int. J. Food Sci. Nutr. 54, 153–158.

Oshodi, A.A., Ogungbenle, H.N., Oladimeji, M.O., 1999. Chemical composition, nutritionally valuable minerals and functional properties of benniseed (*Sesamun radiatum*), pearl millet (*Pennisetum typhoides*) and quinoa (*Chenopodium quinoa*) flours. Int. J. Food Sci. Nutr. 50, 325–331.

Perera, C.O., 2005. Selected quality attributes of dried foods. Dry. Technol. 23, 717–730.

Paśko, P., Sajewicz, M., Gorinstein, S., Zachwieja, Z., 2008. Analysis of selected phenolic acids and flavonoids in *Amaranthus cruentus* and *Chenopodium quinoa* seeds and sprouts by HPLC. Acta Chromatogr. 20, 661–672.

Paśko, P., Bartoń, H., Zagrodzki, P., Gorinstein, S., Folta, M., Zachwieja, Z., 2009. Anthocyanins, total polyphenols and antioxidant activity in amaranth and quinoa seeds and sprouts during their growth. Food Chem. 115, 994–998.

Patzsch, K., Netz, S., Funk, W., 1988. Quantitative HPTLC of sugars. Part 1. Separation and derivatization. J. Planar Chromatogr. 1, 39–45.

Qu, W., Pan, Z., Ma, H., 2010. Extraction modeling and activities of antioxidants from pomegranate marc. J. Food Eng. 99, 16–23.

Repo-Carrasco, R., Espinoza, R.C., Jacobsen, E.-E., 2003. Nutritional value and use of the Andean crops quinoa (*Chenopodium quinoa*) and Kañiwa (*Chenopodium pallidicaule*). Food Rev. Int. 19, 179–189.

Ruales, J., Nair, B.M., 1993. Content of fat, vitamins and minerals in quinoa (*Chenopodium quinoa*, Willd.) seeds. Food Chem. 48, 131–136.

Sattler, S., Gilliland, L., Magallanes-Lundback, M., Pollard, M., DellaPenna, D., 2004. Vitamin E is essential for seed longevity and for preventing lipid peroxidation during germination. Plant Cell 16, 1419–1432.

Schlick, G., Bubenheim, D.L., 1996. Quinoa: candidate crop for NASA's controlled ecological life support systems. In: Janick, J. (Ed.), Progress in New Crops, pp. 632–640.

Stenberg, C., Svensson, M., Johansson, M., 2005. A study of the drying of linseed oils with different fatty acid patterns using RTIR-spectroscopy and chemiluminescence (CL). Ind. Crop. Prod. 21, 263–272.

Tolaba, M.P., Peltzer, M., Enriquez, N., Pollio, M.L., 2004. Grain sorption equilibria of quinoa grains. J. Food Eng. 61, 365–371.

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

Vadivambal, R., Jayas, D.S., 2007. Changes in quality of microwave-treated agricultural products—a review. Biosyst. Eng. 98, 1–16.

Vega-Gálvez, A., Di Scala, K., Rodríguez, K., Lemus-Mondaca, R., Miranda, M., López, J., Pérez-Won, M., 2009a. Effects of air-drying temperature on physicochemical properties, antioxidant capacity and total phenolic content of red pepper (*Capsicum annuum*, L. var. *Hungarian*). Food Chem. 117, 647–653.

Vega-Gálvez, A., San Martín, R., Sanders, M., Miranda, M., Lara, E., in press. Characteristics and mathematical modeling of convective drying of quinoa (*Chenopodium quinoa* Willd.): influence of temperature on the kinetic parameters. J. Food Process. Preserv.

Vilche, C., Gely, M., Santalla, E., 2003. Physical properties of quinoa seeds. Biosyst. Eng. 86, 59–65.

Zeng, H., Nelis, H., Lavens, P., Sorgeloos, P., De Leenheer, A., 1999. Simultaneous determination of a-tocopheryl acetate and tocopherols in aquatic organisms and fish feed. J. Chromatogr. B: Biomed. Sci. Appl. 724, 249–255.

Zielisnki, H., Koslowska, H., 2000. Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. J. Agric. Food Chem. 48, 2008–2016.