This study explored the diversity of the quinoa crop in Chile from a nutritional perspective. Nutritional properties, minerals, vitamins, and saponin content were assessed in seeds of six Chilean quinoa (Chenopodium quinoa Willd.) ecotypes grown in three main production areas with distinctive climatic and edaphic conditions: Ancovinto and Cancosa in the North-Altiplano or High Plateau, Cahuil and Faro in the central coastal area, and Regalona and Villarrica in the south of the country. There were significant differences (P < 0.05) in all the nutritional properties of the quinoa seeds in all three areas. Quinoa of the Villarrica ecotype showed the highest protein content (16.10 g 100 g⁻¹ DM) and the highest content of vitamins E and C (4.644 ± 0.240 and 23.065 ± 1.119 mg 100 g⁻¹ DM, respectively). The highest content of vitamins B₁ (0.648 ± 0.006 mg 100 g⁻¹ DM) and B₃ (1.569 ± 0.026 mg 100 g⁻¹ DM) was found in the Regalona ecotype, while the highest value of vitamin B₂ (0.081 ± 0.002 mg 100 g⁻¹ DM) occurred in the Ancovinto ecotype. Potassium was the most abundant mineral with a maximum value of 2325.56 mg 100 g⁻¹ DM in the Cancosa ecotype. Saponin content varied from 0.84 g 100 g⁻¹ DM in the Villarrica ecotype to 3.91 g 100 g⁻¹ DM in the Cahuil ecotype. Significant differences were found among the Chilean quinoa ecotypes grown under different climatic conditions; however, all the quinoa seeds exhibited a high nutritional value. These results are compatible with the genetic differences previously observed in the three geographical areas under study. Thus, if more studies are conducted to show the particular properties of quinoa from specific areas, it would be possible in the future to coin the term “controlled designation of origin” (appellation d’origine contrôlée) and add commercial value to Chilean quinoa seeds in the domestic and international markets.

Key words: Quinoa, vitamins, minerals, saponin content, nutritional properties.
important minerals (Ca, K, Fe, Mg, Mn, P), isoflavons, and high quality lipids. Such a combination of factors contributes to excellent antioxidant properties and even the saponins in the seed coats, previously considered as antinutrients, can now be extracted for industrial and biomedical use (Jancurová et al., 2009; Vega-Gálvez et al., 2010).

Beyond the highly beneficial nutritional properties of this plant is its extreme agro-ecological adaptability. The nutritional composition of quinoa varies among ecotypes due to strong genetic variability in addition to environmental differences in the Andean region (Repo-Carrasco-Valencia et al., 2010). Similar effects in potato and wheat ecotype composition due to agricultural practices, agroclimatic factors, and soil types have already been reported (Barikmo et al., 2004; Thybo et al., 2006; Galdón et al., 2010). Quinoa varies in Bolivia, Peru, and Ecuador, and can be grown from Colombia to the southern regions of Argentina and Chile as a result of a long-lasting domestication process (Fuentes et al., 2009: 2012). This diversity can be the basis for possible adaptations in the fight against hunger in countries facing similar challenges of drought and salinity under a very diverse array of soil and climatic conditions, for example, in India (Bhargava et al., 2006).

The long Chilean mainland territory between 18° and 43° S lat (stretching over 3000 km) offers an extended natural laboratory to test environmental effects on the nutritional properties of quinoa. Quinoa has been cultivated within this latitudinal distribution since ancient times. Three different biogeographic regions or genetic pools of quinoa are now recognized in Chile, the North-Altiplano, the Center, and the South (Fuentes et al., 2009). Therefore, in this study the seeds of different quinoa ecotypes from Chile’s three production areas were assessed for their nutritional properties, minerals, vitamins, and saponin content; furthermore, different climatic and soil conditions of the three geographical areas were studied to observe if they had any effect on the abovementioned properties.

**MATERIALS AND METHODS**

**Origin of quinoa seeds and sample preparation**

The quinoa seeds were harvested from the three ancestral production areas in Chile, including samples from the three genetic pools (North-Altiplano at 3500 m a.s.l., Center, and South at sea level or low altitude cultivation areas). A total of six quinoa ecotypes were chosen: two North-Altiplano ecotypes from the two localities of Ancovinto and Cancosa (approximately 19° S lat); two Center ecotypes from Cahuil and Faro (approximately 34° S lat); and two South ecotypes from Villarrica (locality approximately 39° S lat) and La Regalona (official variety recorded in a national catalogue of the SAG division of the Chilean Ministry of Agriculture). Samples were analyzed without the industrial dehusking treatment (a process that needs hundreds of kg of seed to be run); they were therefore only visually inspected to discard contaminant particles or impurities. Analytical determinations were carried out on quinoa seeds ground with a grinder (MC0360, UFESA, Zhejiang, China).

**Experimental analytical procedures**

The following were determined: moisture content by the Association of Official Analytical Chemists AOAC method N° 934.06 (AOAC, 1990); crude protein content by the Kjeldahl method with a conversion factor of 6.25 (AOAC Nº 960.52); lipid content by gravimetric measurement following Soxhlet extraction (AOAC Nº 960.39); crude fiber by acid/alkaline hydrolysis of insoluble residues (AOAC Nº 962.09); and crude ash content by incineration in a muffle furnace at 550 °C (AOAC Nº 923.03). All the methodologies followed the recommendations of AOAC (1990). The pH was measured with an EXTECH Instruments microcomputer pH-vision 246072 (Waltham, Massachusetts, USA) (AOAC Nº 981.12), and the titrimetric acidity level of ground grains was measured following the method indicated by AOAC (Nº 925.53) (AOAC, 1990), which was expressed as sulfuric acid. Water activity (a_w) was measured at 25 °C with a water activity meter (Novasina, model TH-500, Pfäffikon, Lachen, Switzerland). Mineral elements (Na, K, Ca, Mg, Cu, Mn, Zn, and Fe) were measured with an atomic absorption spectrophotometer (AAS; Shimadzu Instruments, Inc., SpectrAA-220, Kyoto, Japan) after digestion with a mixture of H2SO4, HNO3, and HClO4. The P content was estimated by a phosphovanadium-molybdenum complex at 466 nm (Shimadzu Instruments, Inc., Spectrophotometer UV-120-02, Kyoto, Japan) as described in previous work (Miranda et al., 2010). The mineral contents were expressed in mg 100 g⁻¹ DM. Vitamin C was determined by certification of NBS (N-bromosuccinimide) according to Barakat et al. (1955) with the following modifications: the oxidizing agent (NBS) was standardized by taking a 10 mL aliquot of a standard ascorbic acid (0.2 mg mL⁻¹) solution which was placed in a flask containing 2 mL KI (4%) solution, 0.8 mL acetic acid (10%) solution, drops of a starch solution (1%) as indicator, and 12 mL of distilled water. This mixture was then titrated with an NBS (0.2 g L⁻¹) solution. The process ended when a permanent blue color was observed. To determine ascorbic acid in the samples, 0.2 g oxalic acid was added, crushed, homogenized, and filtered. The sample solution was placed in an Erlenmeyer flask containing 5 mL KI solution, 2 mL acetic acid solution, drops of starch solution, and 30 mL distilled water; it was then titrated with the NBS solution. Vitamin C content (mg vitamin C 100 g⁻¹ DM) was calculated by Equation [1]:

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

[1]
where T (mL) is the volume of NBS of the standard solution of 2 mg vitamin C (AA); B (mL) is the volume of NBS corresponding to the sample; and M (g) is the sample mass.

Vitamin E (α-tocopherol) content was determined by the high performance liquid chromatography (HPLC)/fluorescence method described by Miranda et al. (2010). Samples were extracted with a methanol-BHT (butylhydroxytoluene) (1 mg mL⁻¹) solution. Vitamin E content was expressed in mg 100 g⁻¹ DM. Furthermore, vitamin B₁ (thiamine), B₂ (riboflavin), and B₃ (niacin) were determined by acid and enzymatic hydrolysis, separated with different HPLC columns in the appropriate mobile phases, and detections were performed at the respective wavelengths in accordance with AOAC N° 942.23, 970.65, and 961.14 (AOAC, 1995), respectively. Vitamin contents were expressed in mg 100 g⁻¹ DM. Saponins were analyzed based on a modified reversed-phase HPLC procedure described by San Martín and Briones (2000). Three grams of grown sample were extracted with an ethanol 50% v/v (1:13) aqueous solution for 2 h with constant stirring. Then the extract was centrifuged (Presvac, Argentina) for 20 min at 20 000 rpm and the supernatant dried at 55 °C for 8 h. The HPLC analyses were done in an Agilent 1100 Series HPLC system that includes a DAD detector set at 210 nm and an automatic injector. The separation was carried out with a Kromasil C-18 RP column (250 × 4.8 mm, 5 µm) at 25 °C. The mobile phase consisted of a 0.1% formic acid solution in water (A) and acetonitrile (B). A gradient system was then applied starting with a ratio of 75:25 (A:B; v/v) up to 65:35 (A:B; v/v) for 15 min with a 0.7 mL min⁻¹ constant flow rate. Next, the ratio was changed to 55:45 (A:B; v/v) and the flow rate to 1.0 mL min⁻¹ for 20 min. The injected sample volume was 5 µL with a concentration of 50 mg mL⁻¹ dry extract. All solvents were of HPLC grade (Merck, Darmstadt, Germany). Results are expressed as g 100 g⁻¹ DM.

**Statistical analysis**

All analyses were triplicated. All the data were expressed as mean ± standard deviation (SD). Analysis of data was performed with Statgraphics Plus 5 (Statistical Graphics Corp., Herndon, Virginia, USA). Significance testing was performed by Fisher’s least significant difference (LSD) test; differences were considered statistically significant when P < 0.05. The multiple range test (MRT) included in the statistical program was applied to prove that there were homogeneous groups in each of the analyzed parameters. Principal Component Analysis was also performed on the complete set of data (24 different proximal, nutritional, and mineral measurements) in order to give an overall proximity/distance figure for the three different samples of each quinoa seed source studied here.

**RESULTS AND DISCUSSION**

**Nutritional composition**

The three different quinoa seed origins correspond to a gradient of higher aridity in the northern High Plateau (150-300 mm annual rainfall) to lesser aridity in the Center (500 mm annual rainfall), and a rainy region in the South (1000-2000 mm annual rainfall) with a concomitant soil salinity gradient which is also normally higher in the High Plateau region (see detailed description in Ruiz-Carrasco et al., 2011). As expected, the nutritional composition of the six quinoa ecotypes from the three different areas (Table 1) indicated lower moisture content for the northern drier genetic area as compared with the central and southern areas. The highest moisture content was found in the ecotypes of the rainiest region of Villarrica with values similar to those reported by Wright et al. (2002) and Vega-Galvez et al. (2010) for quinoa seeds from other Andean regions. The two central ecotypes (Cáhuil and Faro) are similar for most of the data, except for ash and lipid content. Ecotypes of the northern and southern areas showed the greatest difference (P < 0.05), except for ash content. The highest ash content was found in the southern ecotypes (Regalona and Villarrica), an area characterized by soils strongly affected by volcanic activity (Huygens et al., 2008). The ash content of quinoa (3.15-3.65% DM) is similar to that obtained by Wright et al. (2002) and higher than rice (0.5%), wheat (1.8%), and other traditional cereals (Bhargava et al., 2006). The Regalona and Villarrica ecotypes (both from the South) also showed the highest total protein content (14 to 16 g 100 g⁻¹ DM, respectively), which can be due to high N bioavailability in the southern volcanic soils (Huygens et al., 2008); those from the Center showed the lowest protein content (12 g 100 g⁻¹ DM). The protein content of quinoa from the South is similar to wheat and spelt, whereas for the other areas it is similar to barley, oat and

### Table 1. Proximal analysis of six quinoa ecotypes from three geographical areas of Chile.

| Geographical areas | North         | Center      | South        |
|--------------------|---------------|-------------|--------------|
|                    | Ancovinto     | Cancosa     | Cáhuil       | Faro         | Regalona     | Villarrica   |
| Moisture           | 7.74 ± 0.07a  | 9.29 ± 0.06b| 13.17 ± 0.02c| 13.17 ± 0.10c| 14.27 ± 0.03d| 15.18 ± 0.02e|
| Ash                | 3.36 ± 0.06a  | 3.46 ± 0.10ab| 3.15 ± 0.07c| 3.53 ± 0.04bd| 3.61 ± 0.09d  | 3.65 ± 0.09f |
| Protein (N × 6.25) | 12.85 ± 0.28a | 13.59 ± 0.08b| 11.41 ± 0.54c| 11.32 ± 0.19c| 14.66 ± 0.38d| 16.10 ± 0.14e|
| Fat                | 6.24 ± 0.06a  | 5.88 ± 0.13b| 7.15 ± 0.16c| 6.59 ± 0.10d  | 6.42 ± 0.09ad | 5.97 ± 0.07e |
| Crude fiber        | 1.45 ± 0.06a  | 1.91 ± 0.28b| 1.33 ± 0.46a| 1.50 ± 0.14a  | 1.90 ± 0.23b  | 2.81 ± 0.07c |
| Total carbohydrates| 68.36 ± 0.42a | 65.88 ± 0.08b| 63.80 ± 0.68c| 63.89 ± 0.17c| 59.14 ± 0.27d| 56.73 ± 0.19e|

All data are expressed as g 100 g⁻¹ DM. Values are expressed as mean ± standard deviation (n = 3). Different letters indicate significant differences among ecotypes (P < 0.05).
pearl millet flour, all approximately 11-12 g 100 g⁻¹ DM. However, quinoa protein content from all the areas is higher compared with cereal flours, such as rice, maize, and rye (containing 8 to 11 g 100 g⁻¹ DM; Comai et al., 2007). Quinoa seeds contained from 5.88 to 7.15 g 100 g⁻¹ DM fat. This lipid content makes it a high quality edible vegetable oil similar to soybean oil in its fatty-acid composition (Jancurová et al., 2009); however, it is higher than that of cereals such as corn. The Villarrica ecotype has significantly higher crude fiber (2.80 g 100 g⁻¹ DM) content as compared with the other five ecotypes (< 1.9 g 100 g⁻¹ DM) with values similar to those reported by Jancurová et al. (2009). As expected, the highest water activity (a₀) was found in the Regalona ecotype (Table 2), while northern ecotypes showed the lowest a₀ value (also lower moisture content). Since all quinoa seeds showed an a₀ < 0.5, they are relatively stable and less susceptible to spoilage during storage, except for Regalona that could be susceptible to microbial spoilage as well as enzymatic oxidation reactions (Barbosa-Canovas and Vega-Mercado, 2000). In addition, a lower difference is observed in acidity and pH values among the six analyzed ecotypes. These values are important when preparing quinoa flour as a dough additive as it has been suggested for other grain crops (Larsson, 2002).

Mineral contents of quinoa ecotypes are shown in Table 3. The six quinoa ecotypes contain more Ca, Mg, Fe, and P than wheat, barley, oat, rye, or rice (Repo-Carrasco et al., 2003). The data obtained for Mn, Cu, and Zn in this study are in the range of the values reported by Koziol (1992). Mineral contents compared with data by Ruales and Nair (1993) were found to have lower values for Ca, Mg, and Na, but higher values for K. The highest Ca content was found in the Villarrica ecotype, which also had the lowest P content. Potassium was the most abundant in the Cancosa ecotype and P in the Ancovinto ecotype, both from the northern area, whereas higher Mn values were found in the central area. Zinc content was significantly higher in the southern area. This may occur because of the soil type and mineral composition of the areas and/or fertilizer application. Heavy doses of P and K are known to increase vegetative growth without increasing seed yield (Bhargava et al., 2006), and a high K content can be beneficial in the diets of people who take diuretics to control hypertension and suffer from excessive K excretion (Dini et al., 2005). Iron content was also high for the Cancosa ecotype. It is known that iron deficiency anemia (IDA) has been linked to maternal and perinatal mortality, and to impair cognitive skills and physical activity (Ortiz-Monasterio et al., 2007). Iron content in all ecotypes is comparable to wheat, barley, oats, and rice (Repo-Carrasco et al., 2003). It is noteworthy that Na content showed low values in all ecotypes and even in northern ecotypes. Quinoa plants can concentrate or exclude salt from roots and leaves (Ruiz-Carrasco et al., 2011), but they do not seem to translocate Na to the grains. This is important and it can be suggested that a diet with quinoa provides more health benefits than other saltier foods or cereals. In accordance with this fact, the Villarrica ecotype, followed by Regalona, exhibited the best mineral balance. Zinc content ranged from 2.73 to 5.01 mg 100 g⁻¹ DM and showed no significant differences (P > 0.05) between the Ancovinto, Cahuil, and Faro ecotypes. The Villarrica ecotype had the highest value and was similar to values obtained by Fardet et al. (2008) for wheat, oat, barley, and rye. Copper content values were higher than those found by Fardet et al. (2008) for oat and barley.

Table 2 shows vitamin contents (C, B₁, B₂, B₃, and E) of the six quinoa ecotypes from the three different areas. Vitamin C was higher in the Villarrica ecotype and rye (containing 8 to 11 g 100 g⁻¹ DM; Comai et al., 2007). Quinoa flour as a dough additive as it has been suggested for other grain crops (Larsson, 2002).

Table 2. Water activity, pH, and acidity of six quinoa ecotypes from three geographical areas of Chile.

| Geographical areas | North | Center | South |
|--------------------|-------|--------|-------|
| An covinto         |       |        |       |
| Cancosa            | 0.249 ± 0.002a | 0.254 ± 0.001a | 0.465 ± 0.006b |
| pH                 | 6.40 ± 0.02a | 6.29 ± 0.02b | 6.33 ± 0.02c |
| Acidity            | 0.37 ± 0.04ac | 0.28 ± 0.03b | 0.35 ± 0.01a |
| Cahuil             |       |        |       |
| Faro               |       |        |       |
| Regalona           |       |        |       |
| Villarrica         |       |        |       |

1Dimensionless; 2g H₂SO₄ 100 g⁻¹ wet basis. Values are expressed as mean ± standard deviation (n = 3). Different letters indicate significant differences among ecotypes (P < 0.05).

Table 3. Mineral content of six quinoa ecotypes from three geographical areas of Chile.

| Geographical areas | North | Center | South |
|--------------------|-------|--------|-------|
| Ancovinto          |       |        |       |
| Cancosa            | 77.10 ± 2.25a | 105.01 ± 4.56b | 120.33 ± 1.55c |
| Mg                 | 152.31 ± 0.44a | 150.91 ± 0.54a | 160.55 ± 0.72b |
| Na                 | < 0.01 ± 0.00a | < 0.01 ± 0.00a | 18.46 ± 11.68b |
| K                  | 2.188.54 ± 0.67a | 2.325.56 ± 12.22a | 1672.79 ± 0.56b |
| Fe                 | 6.91 ± 0.31a | 7.19 ± 0.15a | 5.06 ± 0.03b |
| Cu                 | 1.52 ± 0.20a | 0.75 ± 0.00b | 0.86 ± 0.04ab |
| Mn                 | 3.75 ± 0.22a | 3.10 ± 0.03b | 4.02 ± 0.17a |
| Zn                 | 3.52 ± 3.99a | 434.65 ± 14.27b | 409.92 ± 8.42b |

2P and K are known to increase vegetative growth without increasing seed yield (Bhargava et al., 2006), and a high K content can be beneficial in the diets of people who take diuretics to control hypertension and suffer from excessive K excretion (Dini et al., 2005). Iron content was also high for the Cancosa ecotype. It is known that iron deficiency anemia (IDA) has been linked to maternal and perinatal mortality, and to impair cognitive skills and physical activity (Ortiz-Monasterio et al., 2007). Iron content in all ecotypes is comparable to wheat, barley, oats, and rice (Repo-Carrasco et al., 2003). It is noteworthy that Na content showed low values in all ecotypes and even in northern ecotypes. Quinoa plants can concentrate or exclude salt from roots and leaves (Ruiz-Carrasco et al., 2011), but they do not seem to translocate Na to the grains. This is important and it can be suggested that a diet with quinoa provides more health benefits than other saltier foods or cereals. In accordance with this fact, the Villarrica ecotype, followed by Regalona, exhibited the best mineral balance. Zinc content ranged from 2.73 to 5.01 mg 100 g⁻¹ DM and showed no significant differences (P > 0.05) between the Ancovinto, Cahuil, and Faro ecotypes. The Villarrica ecotype had the highest value and was similar to values obtained by Fardet et al. (2008) for wheat, oat, barley, and rye. Copper content values were higher than those found by Fardet et al. (2008) for oat and barley.

Table 4 shows vitamin contents (C, B₁, B₂, B₃, and E) of the six quinoa ecotypes from the three different areas. Vitamin C was higher in the Villarrica ecotype

| Geographical areas | North | Center | South |
|--------------------|-------|--------|-------|
| Ancovinto          |       |        |       |
| Cancosa            | 118.08 ± 5.93c | 118.08 ± 5.93c | 118.08 ± 5.93c |
| Mg                 | 155.77 ± 1.36d | 155.77 ± 1.36d | 155.77 ± 1.36d |
| Na                 | < 0.01 ± 0.00a | < 0.01 ± 0.00a | 18.46 ± 11.68b |
| K                  | 2.188.54 ± 0.67a | 2.325.56 ± 12.22a | 1672.79 ± 0.56b |
| Fe                 | 6.91 ± 0.31a | 7.19 ± 0.15a | 5.06 ± 0.03b |
| Cu                 | 1.52 ± 0.20a | 0.75 ± 0.00b | 0.86 ± 0.04ab |
| Mn                 | 3.75 ± 0.22a | 3.10 ± 0.03b | 4.02 ± 0.17a |
| Zn                 | 3.52 ± 3.99a | 434.65 ± 14.27b | 409.92 ± 8.42b |

All data are expressed as mg 100 g⁻¹ DM. Values are expressed as mean ± standard deviation (n = 3). Different letters indicate significant differences among ecotypes (P < 0.05).
with significant differences (P < 0.05) compared with the rest of the ecotypes. The Faro ecotype had significantly lower vitamin C content than the other ecotypes. The variations among ecotypes for vitamin C content are due to the biological diversity of quinoa ecotypes in Chile. According to Jiménez et al. (2009), variations can be attributed to genetic or environmental growth conditions. Lee and Kader (2000) reported that some citrus fruit contained more vitamin C when grown under cool temperatures rather than hot temperatures. The vitamin C content found in this investigation was similar to other data reported by Ruales and Nair (1993) for quinoa seed (16.4 mg AA 100 g⁻¹ DM) and Dini et al. (2010), who worked with quinoa from Ecuador and Peru (13.0 and 12.0 mg AA 100 g⁻¹ DM, respectively). Lower values of vitamin C have also been reported in the literature by Koziol (1992) (4 to 5 mg AA 100 g⁻¹ DM). Vitamin C losses increase with extended storage, higher temperature, low relative humidity, physical damage, chilling injury, large genotypic variation, and climatic conditions; all these factors are responsible for the wide variation in vitamin C content (Lee and Kader, 2000; Dumas et al., 2003; Xu et al., 2008). Wall (2006), in his work with fruit ecotypes grown in Hawaii, commented that ascorbic acid levels in fruit are influenced by the availability of light to the crop and to individual fruits. In addition, an excess of soil N or P tends to decrease ascorbic acid content in fruit, while an excess of K could increase vitamin C content.

The B-group vitamins are water-soluble molecules and play an important metabolizing role, particularly in the metabolism of carbohydrates (thiamine or B1), proteins, and fats (riboflavin or B2, and pyridoxine). Table 4 shows vitamin B1, B2, and B3 contents in the quinoa ecotypes. Vitamin B1 content was the highest in the Regalona seeds (hybrid variety) probably because of a generally better soil quality in southern Chile and with higher organic matter content as compared with soils of the drier northern areas, which is a typical condition of arid zones (Fernández-Cirelli et al., 2009). There were no significant differences (P > 0.05) in vitamin B1 content between central area ecotypes. Vitamin B1 content is comparable to values of 0.38 mg 100 g⁻¹ DM by Ruales and Nair (1993) with 0.4 mg 100 g⁻¹ DM by Ruales and Nair (1993). Batifoulier et al. (2006) reported values for vitamin B1 that ranged from 0.259 to 0.613 mg 100 g⁻¹ DM for 49 northwestern European wheat ecotypes, while Lebiedzińska and Szefer (2006) reported values from 0.344 to 0.369 mg 100 g⁻¹ DM for barley. Vitamin B2 values are much lower than those reported by Koziol (1992) and Ruales and Nair (1993) with 0.39 mg to 0.2 mg 100 g⁻¹ DM. Vitamin B3 (niacin) supply is low on quinoa ecotypes, even lower than those reported by Lebiedzińska and Szefer (2006) on brown rice and barley with 4.36 and 4.07 mg 100 g⁻¹ DM, respectively. Koziol (1992) reported 1.06 mg 100 g⁻¹ DM for quinoa B3 content. Batifoulier et al. (2006) reported significant differences in vitamin B contents in wheat due to variety, growing location (for thiamine and riboflavin), soil type, and years (for thiamine and pyridoxine).

Vitamin E is a well-known antioxidant that acts as a free scavenger by preventing the oxidation of polysaturated lipids by free radicals such as the hydroxyl radical OH (Fardet et al., 2008). As shown in Table 4, quinoa vitamin E values ranged from 2.44 to 4.64 mg 100 g⁻¹ DM with the Villarrica ecotypes showing the highest value. Similar levels of vitamin E were reported by Koziol (1992) for quinoa with 5.37 mg 100 g⁻¹ DM, while wheat, rice and barley had lower values (1.15 mg, 0.18 mg, and 0.35 mg 100 g⁻¹ DM, respectively).

Figure 1 shows that the saponin content was significantly different (P < 0.05) among quinoa ecotypes; it ranged from 0.84% to 3.91% DM for the Villarrica and Cahuil ecotypes, respectively. Analysis of saponin content in quinoa ecotypes indicates that variability among ecotypes is important. Nevertheless, abrasive procedures to remove saponin might cause nutrient losses such as Ca, but they have no effects on P, K, and Mg localized in the seed embryo or on some vitamins because they are found

Table 4. Vitamin content of six quinoa ecotypes from three geographical areas of Chile.

| Vitamin   | North         | Center        | South        |
|-----------|---------------|---------------|--------------|
|           | Ancovinto     | Cancosa       | Regalona     | Villarrica   |
| Vitamin C | 16.702 ± 0.001a | 16.204 ± 1.116a | 17.011 ± 1.121a | 23.065 ± 1.119c |
| Vitamin B1| 0.452 ± 0.018a | 0.485 ± 0.006b | 0.568 ± 0.006d | 0.349 ± 0.006e |
| Vitamin B2| 0.081 ± 0.002a | 0.073 ± 0.002b | 0.056 ± 0.002e | 0.074 ± 0.001b |
| Vitamin B3| 0.994 ± 0.046a | 0.562 ± 0.013b | 1.569 ± 0.026c | 1.418 ± 0.005f |
| Vitamin E | 2.465 ± 0.184a | 2.587 ± 0.108a | 3.051 ± 0.079b | 4.644 ± 0.240c |

All data are expressed as mg 100 g⁻¹ dm. Values are expressed as mean ± standard deviation (n = 3). Different letters indicate significant differences among ecotypes (P < 0.05).
The rich seed diversity of quinoa ecotypes produced in different biogeographical areas of Chile also differed in their nutritional properties, minerals, vitamins, and saponin contents, thus in their nutritional value. However, all ecotypes showed an outstanding nutritional quality, higher than that of most traditional cereals. Such nutritional and chemical features of quinoa seeds from very diverse geographical areas offer excellent opportunities for genetic improvement trials and the creation of new and improved varieties.

CONCLUSIONS

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CONCLUSIONS

The overall nutritional and mineral dataset used to plot the first and second main axes of the Principal Component Analysis (Figure 2) clearly separated the three geographical sources of quinoa used in this study. In addition, there is a clear separation between Regalona and Villarrica, because of the hybrid state of Regalona. The overall picture also correlates well with the genetic differences previously observed among quinoa ecotypes of the country’s three regions (Fuentes et al., 2012).

Figure 2. Two main axes of the Principal Component Analysis constructed from the overall set of 24 measured nutritional values applied to the three samples of each quinoa origin where open ovals enclose the three main geographical origins: Squares represent the High Plateau (two localities, AN: Ancovinto, CA: Cancosa), triangles represent the Center (two localities, FA: Faro, CH: Cáhuil), and circles represent the South (one locality, VI: Villarrica, and one hybrid variety, RE: Regalona).


cs of quinoa (Chenopodium quinoa Willd.) of three geographical areas of Chile. The diversity in the cultivation of quinoa (Chenopodium quinoa Willd.) of Chile was explored since a perspective nutritional. In this context the properties nutritional also play the contents of minerals, vitamins, and saponin were evaluated in the seeds of all six ecotypes chilenos de quinoa, cultivated in the three main geographical zones of production with conditions edofoclimáticas distintas: Ancovinto and Cancosa of the altiplano norte, Cahuil and Faro of the coast, central and Villarrica in the south of the country. Hubo diferencias significativas (P < 0.05) in all the properties nutritional in the seeds of all the zones. The ecotype Villarrica has the greatest content of protein (16.10 g 100 g-1 MS) and vitamin E and C (4.644 ± 0.240 g 100 g-1 MS, respectively). The greater content of vitamin B1 (0.648 ± 0.006 g 100 g-1 MS) and B3 (1.569 ± 0.026 g 100 g-1 MS) was found in the ecotype Regalona, and the greater content of vitamin B2 (0.081 ± 0.002 mg 100 g-1 MS) in the ecotype Ancovinto. K F was the mineral more abundant with a value of 2325.56 mg 100 g-1 MS in the ecotype Cancosa. The content of saponin fluctuated between 0.84 g 100 g-1 MS in the ecotype Villarrica and 3.91 g 100 g-1 MS in the ecotype Cahuil. Hubo diferencias significativas entre los ecotipos chilenos de quinoa cultivados bajo diferentes condiciones climáticas. No obstante, las semillas de quinoa de cualquier zona demuestran un alto valor nutricional. Estos resultados son relevantes en el sentido que se puede afirmar que la quinoa tiene propiedades típicas de la zona de cultivo. Los resultados obtenidos son coincidentes con diferencias genéticas observadas previamente entre las tres localidades muestreadas. Si se agregan más estudios de este tipo podría acuñarse el término de “denominación de origen controlado” (appellation d’origine contrôlée) y dar un valor agregado a las semillas de quinoa de Chile tanto en el mercado nacional como internacional.

Palabras clave: quinoa, vitaminas, minerales, contenido de saponina, propiedades nutritionales.

LITERATURE CITED

AOAC. 1990. Official method of analysis. 15th ed. Association of Official Analytical Chemists (AOAC), Washington, DC, USA.
AOAC. 1995. Official method of analysis. 16th ed. Association of Official Analytical Chemists (AOAC), Washington, DC, USA.
Barbosa-Canovas, G.V., and H. Vega-Mercado. 2000. Deshidratación de alimentos. Editorial ACRIBIA S.A., Zaragoza, España.
Barakat, M.Z., M.F.A. El-Wahab, and M.M. El-Sadr. 1955. Action de N-bromosuccinimide on ascorbic acid. Biochemistry Department, Faculty of Medicine, Abbassia, Cairo, Egypt. Analytical Chemistry 27:536-540.
Barikmo, I., F. Ouatatarab, and A. Oshaug. 2004. Protein, carbohydrate and fibre in cereals from Mali - how to fit the results in a food composition table and database. Journal of Food Composition and Analysis 17:291-300.

Batifoulier, F., M.A. Verny, E. Chanlaid, C. Rémyès, and C. Demigné. 2006. Variability of B vitamin concentrations in wheat grain, milling fractions and bread products. European Journal of Agronomy 25:163-169.

Bhargava, A., S. Shukla, and D. Otri. 2006. *Chenopodium quinoa*: an Indian perspective. Industrial Crops and Products 23:73-87.

Cupitès, V.D., K.D. Coelho, A.C. Guerra-Matías, and J.A.G. Aréas. 2008. Effects of processing methods on amaranth starch digestibility and predicted glycemic Index. Journal of Food Science 73:H160-H164.

Chapagain, A.K., and A.Y. Hoekstra. 2008. The global component flows between nations as a result of trade in agricultural and industrial products. Water International 33:19-32.

Comai, S., A. Bertazzo, L. Bailoni, M. Zancato, C.V.L. Coata, and G. Allegri. 2007. The content of proteinic and nonproteic (free and protein-bound) tryptophan in quinoa and cereal flours. Food Chemistry 100:1392-1355.

Dini, I., G.C. Tenore, and A. Dini. 2005. Nutritional and antinutritional composition of Kancolla seeds: an interesting and underexploited Andine food plant. Food Chemistry 92:125-132.

Dini, I., G.C. Tenore, and A. Dini. 2010. Antioxidant compound contents and antioxidant activity before and after cooking in sweet and bitter *Chenopodium quinoa* seeds. LWT- Food Science and Technology 43:447-451.

Dumas, Y., M. Madomo, G. Di Lucca, and P. Grolier. 2003. Review: Effects of environmental factors and agricultural techniques on antiooxidative content of tomatoes. Journal of the Science of Food and Agriculture 83:369-382.

FAO. 2011. The state of food and agriculture. 147 p. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fardet, A., E. Rock, and C. Rémésy. 2008. Is the antioxidant potential of whole-grain cereals and cereal products well reflected *in vivo*? Journal of Cereal Science 48:258-276.

Fernández-Cirelli, A., J.L. Arumi, D. Rivera, and P.W. Booches. 2009. Environmental effects of irrigation in arid and semi-arid Regions. Chilean Journal of Agricultural Research 69:27-40.

Fuentes, F.F., E.A. Martínez, and P.J. Hinrichsen. 2010. Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.) seeds. Journal of Food Process Engineering ISSN 1745-4530. doi:10.1111/j.1745-4530.2012.00673.x.

Guldán, B.R., D.R. Mesa, E.R. Rodríguez, and C.D. Romero. 2010. Influence of the cultivar on the organic acid and sugar composition of potatoes. Journal of the Science of Food and Agriculture 90:2361-2369.

Hirose, Y., T. Fujita, T. Ishii, and N. Ueno. 2010. Antioxidative properties and flavonoid composition of *Chenopodium quinoa* seeds cultivated in Japan. Food Chemistry 119:1300-1306.

Huygens, D., P. Boeckx, L. Bailoni, M. Zancato, C.V.L. Coata, and G. Allegri. 2007. The content of proteinic and nonproteic (free and protein-bound) tryptophan in quinoa and cereal flours. Food Chemistry 100:1392-1355.

Kuljanahagavad, T., P. Thongphasuk, W. Chamulitrat, and M. Wink. 2008. Triterpene saponins from *Chenopodium quinoa* Willd. Phytochemistry 69:1919-1926.

Lee, S.K., and A.A. Kader. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology 20:207-220.

Martínez, E.A., W. Fan, G. Zhao, and C. Torre. 2009. Re-introduction of *Chenopodium quinoa* Willd. into arid Chile: Cultivation of two lowland races under extremely low irrigation. Journal of Agronomy and Crop Science 195:1-10.

Martínez, E.A., V. Vega-Gálvez, J. López, G. Parada, M. Sanders, M. Aranda, et al. 2010. Impact of air-drying temperature on nutritional properties, total phenicolic content and antioxidant capacity of quinoa seeds (*Chenopodium quinoa* Willd.). Industrial Crops and Products 32:258-263.

Ortiz-Monasterio, J.L., N. Palacios-Rojas, E. Meng, K. Pixley, R. Troughton, and P.J. Hinrichsen. 2007. Enhancing the mineral and vitamin content of wheat and maize through plant breeding. Journal of Cereal Science 46:293-307.

Pezzini, C., A. Vega-Gálvez, M. Miranda, R. Lemus-Mondaca, M. Lozano and K. Ah-Hen. 2012. A kinetic approach to saponin extraction during washing of quinoa (*Chenopodium quinoa* Willd.) seeds. Journal of Food Process Engineering ISSN 1745-4530. doi:10.1111/j.1745-4530.2012.00673.x.

San Martín, R., and R. Briones. 2000. Quality of commercial quinoa (*Chenopodium quinoa*) and kañiwa (*Chenopodium pallidicaule*) germplasm using reverse phase high performance liquid chromatography. Food Chemistry 73:H160-H164.

Sammán, N.C. 2009. Re-introduction of *Chenopodium quinoa* Willd. into arid Chile: Cultivation of two lowland races under extremely low irrigation. Journal of Agronomy and Crop Science 195:1-10.

San Martín, R., and R. Briones. 2000. Quality of commercial quinoa (*Chenopodium quinoa*) and kañiwa (*Chenopodium pallidicaule*) germplasm using reverse phase high performance liquid chromatography. Food Chemistry 73:H160-H164.