Nutrition facts and functional potential of quinoa (Chenopodium quinoa Willd.), an ancient Andean grain: a review

Antonio Vega-Gálvez, Margarita Miranda, Judith Vergara, Elsa Uribe, Luis Puente and Enrique A Martínez

Abstract

Quinoa, Chenopodium quinoa Willd., is an Amaranthacean, stress-tolerant plant cultivated along the Andes for the last 7000 years, challenging highly different environmental conditions ranging from Bolivia, up to 4.500 m of altitude, to sea level, in Chile. Its grains have higher nutritive value than traditional cereals and it is a promising worldwide cultivar for human consumption and nutrition. The quinoa has been called a pseudo-cereal for botanical reasons but also because of its unusual composition and exceptional balance between oil, protein and fat. The quinoa is an excellent example of ‘functional food’ that aims at lowering the risk of various diseases. Functional properties are given also by minerals, vitamins, fatty acids and antioxidants that can make a strong contribution to human nutrition, particularly to protect cell membranes, with proven good results in brain neuronal functions. Its minerals work as cofactors in antioxidant enzymes, adding higher value to its rich proteins. Quinoa also contains phytohormones, which offer an advantage over other plant foods for human nutrition.

Keywords: Andean crops; functional foods; human nutrition; physiologically active compounds; quinoa; stress tolerance

INTRODUCTION

A strong earthquake and tsunami recently impacted our Chilean territory. This strike left two million people without shelter and food supplies. This situation is imposing a large-scale challenge for good-quality food to be readily available. One alternative source of staple food is Chenopodium quinoa, a crop present in Chile, although poorly known, and it emerges as a good food candidate due to its exceptional nutritive value but also due to the strong tolerance to stressing abiotic conditions. The genus Chenopodium is distributed worldwide and includes 250 species. This review focuses on the nutritional and functional properties of Chenopodium quinoa, which is a tetraploid species, a close relative of beets and amaranth that originated in the Andean region of Bolivia and Peru. It has been cultivated in this area for the last 5000–7000 years and from there it was transmitted by livestock migrations and traded to other ancient cultures to the northern (Venezuela) and southern extremes of South America, namely Argentina and Chile. This is why it is known with different local names, according to voices of different cultures such as ‘tupapa supha’ in Aymará, ‘suba’ in Chibcha, ‘ayara’ in Quechua, ‘dawe’ in Mapudungun (southern Chile) or just quinoa or quinua. This plant was called by the Incas ‘the mother grain’ and it was given a sacred status, a gift from their gods. After the Spanish conquest, it remained only where Europeans could not arrive and introduce grains such as wheat, rye and oat (Altiplano in the High Andes above 3500 m above sea level (a.s.l.)) or in isolated regions where roads are cut off in winter or where the ancient cultures still remain strong and attached to their agricultural practices and to their traditional food consumption habits (aymaras in the northern Chilean Altiplano, isolated farmers of the coast of central Chile and within the mapuches people in southern Chile). Concerning the more accessible arable lands, the European-introduced crops replaced quinoa. This separation and subsequent isolation determined a strong pattern of genetic differentiation: the high Andes ecotypes are genetically different from the southern ones, as detected by microsatellites, a kind of highly polymorphic molecular marker. About 3000 varieties are conserved in South American germplasm banks assuring conservation and characterization, and opening possibilities for informed interchange of seed materials. Quinoa has been authorized to be sown in Europe, North America, Asia and Africa. Particularly in Europe a project was approved in 1993 entitled ‘Quinoa: a multipurpose crop for the European Community’, for agriculture diversification.

While quinoa is an ancient crop, available technical information regarding the properties of chemical composition and functional properties is limited. Therefore, this work is an updated review of the chemical composition, physiologically active compounds and some functional properties of Chenopodium quinoa that gives this grain outstanding potential in human nutrition. Its varied

Correspondence to: Antonio Vega-Gálvez, Department of Food Engineering, Universidad de La Serena, Av. Raúl Bitrán s/n, Box 599, La Serena, Chile. E-mail: a.vegag@userena.cl

a Department of Food Engineering, Universidad de La Serena, La Serena, Chile
b Department of Food Science and Chemical Technology, Universidad de Chile, 7500906, Santiago, Chile.
c Center for Advanced Studies in Arid Zones, CEAZA, Universidad de La Serena, La Serena, Chile
nutritional properties are better understood when the botanical and environmental diversity of quinoa is also known. We start our review with a brief description on its great adaptation to abiotic stress, a particularly relevant aspect in a world with strong trends towards increased soil degradation, desertification and critical climatic change.

BOTANICAL AND AGRONOMICAL DIVERSITY OF QUINOA IN VARIED AND STRESSING ENVIRONMENTAL CONDITIONS

Quinoa is a plant that produces grains even if cultivated up to 4500 m a.s.l. and with higher nutritive value than traditional cereals, as for instance Amarilla de Marangani and Blanca de Junin, two commercial varieties grown in greater proportion in the Andes of southern Peru. Most varieties of quinoa commonly differ in the morphology, phenology and the chemical composition of the tissues.

The quinoa (a dicot plant) is not a true grain, like typical cereal (monocot) grains, it is rather a fruit, so that it has been called a pseudo-cereal and even a pseudo-oilseed. This is also because of its unusual composition and exceptional balance between oil, protein and fat.

Quinoa, according to sowing density, can grow from 1 to 3 m high. The seeds can germinate very fast, i.e. in a few hours after having been exposed to moisture. The roots can reach a depth of up to 30 cm if sown deep in the soil. The stem is cylindrical, 3.5 cm in diameter; it can be either as a straight stem or branched and its color is variable. Depending on the variety, it changes from white, yellow or light brown to red. Leaves are shaped like a goose foot. The flowers are incomplete and do not have petals. Quinoa has both hermaphrodite flowers, located at the distal end of a group, and female flowers, located at the proximal end (Fig. 1).

Quinoa seeds are round and flattened, and they may measure from about 1.5 mm in diameter to 4 mm; about 350 seeds weigh 1 g. Seed size and color are variable. Seed colors go from white to grey and black, potentially having tones of yellow, rose, red and purple and violet, often with very colorful mixes in the same panicule, where black is dominant over red and yellow, which in turn are dominant to white seed color (as seen in Fig. 1). The classification of quinoa was first made from the color of the plant and fruits. Subsequently, it was based on the morphological types of the plant. Despite the wide variation observed, quinoa is considered to be one single species.

The cultivation of quinoa is related to crop rotation with potatoes, also a crop of Andean origin. This is a common practice, which improves quinoa yield and preserves soil fertility. Moreover, the biological cycle of several pathogenic microorganisms is broken down.

The cultivation cycle lasts 8 months in the high Andes but it can be as short as 4 months in arid central Chile. It is sown in November in the Altiplano, close to the Equator (close to 12 h daylight) and from September to August in the lowlands of more southern latitudes (longer spring and summer days). Maturation and harvest, according to daylength, is done in May in the Altiplano and from February to March in the center–south of Chile. Here, some ecotypes could attain maturity and seed production under irrigation equivalent to only 50 mm of rainfall per season, which is an extremely low irrigation for any crop species. It also seems to have exceptional physiological adaptations for high water use efficiency under stomatal closure besides efficient roots for water capture, as earlier pointed out by Wood. In arid regions the addition of organic matter also increases water use efficiency and grain yields. Strong tolerance has been also demonstrated for other stressing conditions such as salty soils and cold climate, which improves quinoa yield and preserves soil fertility. Moreover, the biological cycle of several pathogenic microorganisms is broken down.

As mentioned above, quinoa is a drought-tolerant crop having low water requirements, although yield is significantly affected by irrigation. It is able to develop even in regions where the annual rainfall is in the range of 200–400 mm. Although it has been proven that it can be grown in southern Chile with an annual precipitation as high as 3000 mm. Although having good a response in poor soils, quinoa does respond well to nitrogen fertilization. Thus nitrogen significantly increases seed production and protein content.

BIOCHEMICAL AND NUTRITIONAL COMPOSITION OF QUINOA

Consumption of seeds is the most common use of quinoa (Table 1) and the review will be focused on its composition (Table 2). However, consumption of sprouts is becoming increasingly

---

**Table 1.** Main uses of quinoa

<table>
<thead>
<tr>
<th>Main uses</th>
<th>Component implied</th>
<th>Plant organ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foods and drinks</td>
<td>Vitamins</td>
<td>Seeds and leaves</td>
</tr>
<tr>
<td></td>
<td>Proteins</td>
<td>Seeds and leaves</td>
</tr>
<tr>
<td>Animal food</td>
<td>Vitamins</td>
<td>Whole plant</td>
</tr>
<tr>
<td></td>
<td>Proteins</td>
<td>Whole plant</td>
</tr>
<tr>
<td>Medicine</td>
<td>Immune system</td>
<td>Leaves and seeds</td>
</tr>
<tr>
<td></td>
<td>Skin applications</td>
<td>Leaves and seeds</td>
</tr>
<tr>
<td></td>
<td>Circulatory applications</td>
<td>Leaves and seeds</td>
</tr>
<tr>
<td>Repellent</td>
<td>Insects</td>
<td>Leaves and seed coat</td>
</tr>
</tbody>
</table>

---

FAO.

---

**Figure 1.** Quinoa panicules (*Chenopodium quinoa* Willd).
and methionine even though there is considerable variation between these varieties in the contents of such amino acids. Dini et al.\textsuperscript{30} using decorticated quinoa, found that the composition of quinoa is nutritionally comparable or superior to other commonly consumed cereals. When extracted, quinoa proteins solubility could be improved by enzymatic hydrolisis.\textsuperscript{41} Quinoa is also considered as one of the best leaf protein concentrate sources and so has potential as a protein substitute for food and fodder and in the pharmaceutical industry.\textsuperscript{42}

### Carbohydrates

Starch, the major biopolymeric constituent of plants (grains, seeds and tubers) occurs typically as granular forms of various shapes and sizes.\textsuperscript{43} Starch provides the major source of physiological energy in the human diet and accordingly it is classified, in general, as available carbohydrate.\textsuperscript{44} In quinoa, starch is the most important carbohydrate in all grains, making up approximately 58.1–64.2\% of the dry matter, according to studies of Repo-Carrasco et al.\textsuperscript{33} of which 11\% is amylose.\textsuperscript{45,46} Granules of quinoa starch have a polygonal form with a diameter of 2 µm, being smaller than starch of the common grains. The extremely small size of the starch granule can be beneficially exploited by using it as a biodegradable filler in polymer packaging. Its excellent freeze–thaw stability makes it an ideal thickener in frozen foods and other applications where resistance to retrogradation is desired.\textsuperscript{47} In addition, quinoa flour contains high percentages of D-xylose and maltose, and low contents of glucose and fructose, which allows its use in malted drink formulations.\textsuperscript{48} Also, its content of D-ribose and D-galactose and maltose would result in a low fructose glycemic index. Repo-Carrasco et al.\textsuperscript{33} reported for quinoa 1.70 mg 100 g\textsuperscript{−1} of glucose, 0.20 mg 100 g\textsuperscript{−1} of fructose, 2.90 mg 100 g\textsuperscript{−1} of saccharose and 1.40 mg 100 g\textsuperscript{−1} of maltose.

### Minerals

Quinoa has a high content of calcium, magnesium, iron, copper and zinc.\textsuperscript{27,29,33,49} Many minerals in quinoa are found at concentrations greater than that reported for most grain crops. Providing they are found in bioavailable forms, calcium, magnesium and potassium are found in sufficient quantities for a balanced human diet.\textsuperscript{38}
Vitamins

Vitamins are compounds essential for the health of humans and animals; according to their solubility they are divided into two groups: hydro- and lipo-soluble. Traditionally, vitamins have been among the most widely applied chemical agents to enhance the nutritional values of food products. Some vitamins may also help to lower the levels of toxic compounds formed in chemical reactions such as the Maillard reaction. Table 5 shows the main vitamins found in quinoa. The quinoa is found to be rich in α-carotene and niacin. Ruales and Nair\textsuperscript{29} have reported appreciable amounts of thiamin (0.4 mg 100 g\textsuperscript{-1}), folic acid (78.1 mg 100 g\textsuperscript{-1}) and vitamin C (16.4 mg 100 g\textsuperscript{-1}). Koziol\textsuperscript{27} compared the vitamin contents of quinoa with some cereals (rice, barley and wheat) and reported that quinoa contains substantially more riboflavin (B\textsubscript{2}), α-tocopherol (vitamin E) and carotene than those cereals. In terms of a 100 g edible portion, quinoa supplies 0.20 mg vitamin B\textsubscript{6}, 0.61 mg pantothenic acid, 23.5 g folic acid and 7.1 g biotin.\textsuperscript{10} Repo-Carrasco \textit{et al.}\textsuperscript{33} also reported that quinoa is rich in vitamin A, B\textsubscript{2} and E. The content of vitamin E in quinoa is important since this vitamin acts as an antioxidant at the cell membrane level, protecting the fatty acids of the cell membranes against damage caused by free radicals.\textsuperscript{33}

**Table 4.** Mineral composition (mg kg\textsuperscript{-1} dry weight)

<table>
<thead>
<tr>
<th>References</th>
<th>Ca</th>
<th>P</th>
<th>Mg</th>
<th>Fe</th>
<th>Zn</th>
<th>K</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koziol\textsuperscript{27}</td>
<td>1487</td>
<td>3837</td>
<td>2496</td>
<td>132</td>
<td>44</td>
<td>9267</td>
<td>51</td>
</tr>
<tr>
<td>Repo-Carrasco \textit{et al.}\textsuperscript{33}</td>
<td>940</td>
<td>1400</td>
<td>2700</td>
<td>168</td>
<td>48</td>
<td>ND</td>
<td>37</td>
</tr>
<tr>
<td>Ruales and Nair\textsuperscript{17}</td>
<td>874</td>
<td>5300</td>
<td>260</td>
<td>81</td>
<td>36</td>
<td>12000</td>
<td>10</td>
</tr>
<tr>
<td>Bhargava \textit{et al.}\textsuperscript{10}</td>
<td>1274</td>
<td>3869</td>
<td>ND</td>
<td>20</td>
<td>48</td>
<td>6967</td>
<td>ND</td>
</tr>
<tr>
<td>Konishi \textit{et al.}\textsuperscript{50}</td>
<td>863</td>
<td>4110</td>
<td>5020</td>
<td>150</td>
<td>40</td>
<td>7320</td>
<td>ND</td>
</tr>
<tr>
<td>Dini \textit{et al.}\textsuperscript{30}</td>
<td>275</td>
<td>4244</td>
<td>ND</td>
<td>26</td>
<td>27.5</td>
<td>75</td>
<td>ND</td>
</tr>
<tr>
<td>Sanders\textsuperscript{32}</td>
<td>565</td>
<td>4689</td>
<td>1760</td>
<td>14</td>
<td>28</td>
<td>11930</td>
<td>2</td>
</tr>
<tr>
<td>González \textit{et al.}\textsuperscript{24}</td>
<td>1020</td>
<td>1400</td>
<td>ND</td>
<td>105</td>
<td>ND</td>
<td>8225</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND, not detected.

**Table 5.** Vitamin concentration (mg 100 g\textsuperscript{-1} dry weight)

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Koziol\textsuperscript{27}</th>
<th>Ruales and Nair\textsuperscript{17}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascorbic acid (C)</td>
<td>4.0</td>
<td>16.4</td>
</tr>
<tr>
<td>α-Tocopherol (E)</td>
<td>5.37</td>
<td>2.6</td>
</tr>
<tr>
<td>Thiamin (B\textsubscript{1})</td>
<td>0.38</td>
<td>0.4</td>
</tr>
<tr>
<td>Riboflavin (B\textsubscript{2})</td>
<td>0.39</td>
<td>ND</td>
</tr>
<tr>
<td>Niacin (B\textsubscript{3})</td>
<td>1.06</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND, not detected.

**Table 6.** Unsaturated fatty acid (g 100 g\textsuperscript{-1} of oil extract)

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oleic</td>
<td>23.3</td>
</tr>
<tr>
<td>Linoleic</td>
<td>53.1</td>
</tr>
<tr>
<td>Linolenic</td>
<td>6.2</td>
</tr>
</tbody>
</table>

**Lipids**

Oil content in quinoa ranges from 1.8% to 9.5%, with an average of 5.0–7.2%, which is higher than that of maize (3–4%).\textsuperscript{27} Numerous fatty acids are synthesized by the human body, and these are known as ‘non-essential fatty acids’ because they are not essentially needed in the diet.\textsuperscript{54} However, because the body cannot produce all the types of fatty acids it requires, some must come from the diet; these fatty acids are called ‘essential fatty acids’ or EFAs (Table 6). The EFAs are metabolized to longer-chain fatty acids of 20 and 22 carbon atoms.\textsuperscript{35} There are two known families of EFAs: omega-3 (ω-3) and omega-6 (ω-6).\textsuperscript{55} Linoleic acid is metabolized to arachidonic acid and linolenic acid to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Linoleic acid is one of the most abundant polysaturated fatty acids identified in quinoa; polysaturated fatty acids have several positive effects on cardiovascular disease and improved insulin sensitivity.\textsuperscript{37} The reported total lipid content in quinoa is 14.5% with an unsaturated level of about 70%, having linoleic and oleic acids in percentages of 38.9% and 27.7% respectively.\textsuperscript{30} While Ahamed \textit{et al.}\textsuperscript{57} reported in another study that quinoa fat had a high content of oleic acid (24%) and linoleic acid (52%). All fatty acids present in quinoa are well protected by the presence of vitamin E, which acts as a natural antioxidant.\textsuperscript{55} Repo-Carrasco \textit{et al.}\textsuperscript{33} reported from Peruvian quinoa the highest percentage of fatty acids being 50.2% for linoleic acid (ω-6), 4.8% of linolenic acid (ω-3).

**ANTIOXIDANT ACTIVITY**

Recently, much attention has been given to naturally occurring antioxidants, which may play an important role in inhibiting both free radicals and oxidative chain reactions within tissues and membranes.\textsuperscript{57} Therefore, the evaluation of antioxidant activities of extracts and fractions is considered an important step prior to the isolation of antioxidant phytochemicals they contain. Antioxidants are compounds that can delay or inhibit the oxidation of lipids or other molecules by inhibiting the initiation or propagation of free radicals. Antioxidants act by donating electrons or hydrogen atoms to free radicals, thus terminating the free radical chain reaction. Antioxidants can be classified into two main categories: enzymatic and non-enzymatic antioxidants. The former include enzymes such as catalase, superoxide dismutase, and glutathione peroxidase, while non-enzymatic antioxidants include nutrients such as vitamin C, vitamin E, β-carotene, and selenium. These antioxidants can be divided into two groups: hydrophilic and lipophilic antioxidants. Hydrophilic antioxidants are those that can easily penetrate cell membranes and reach the site of damage, while lipophilic antioxidants are those that are more effective in protecting cell membranes from lipid peroxidation. The antioxidant activity of quinoa has been studied using various methods, such as the DPPH radical scavenging assay, the ABTS radical scavenging assay, and the lipid peroxidation assay. The results showed that quinoa has a high antioxidant activity, which may be attributed to the presence of phenolic compounds, flavonoids, and carotenoids. These compounds are known to act as antioxidants by donating electrons or hydrogen atoms to free radicals, thus terminating the free radical chain reaction. The antioxidant activity of quinoa has been found to be higher than that of many other cereals, such as rice, barley, and wheat. This may be due to the high content of phenolic compounds and carotenoids in quinoa. Quinoa has also been found to have a high content of α-tocopherol (vitamin E), which is a powerful antioxidant that protects cell membranes from lipid peroxidation. The antioxidant activity of quinoa has been found to be highest in the quinoa germ, which is the outer part of the quinoa grain. The antioxidant activity of quinoa has been found to vary depending on the variety of quinoa, the geographical location, and the processing method. These factors can affect the content of phenolic compounds and carotenoids, which are important for the antioxidant activity of quinoa. Quinoa has been found to have a high potential for use as a natural antioxidant in the food industry, where it can be used to improve the shelf life of food products by inhibiting lipid oxidation.
of oxidizing chain reactions. When added to foods, antioxidants minimize rancidity, delay the formation of toxic oxidation products, maintain nutritional quality and increase shelf life.52

Pasko et al.31 showed that pseudocereal seeds and sprouts show relatively high antioxidant activity. Nsimba et al.57 evaluated the antioxidant activity of various extracts from quinoa (Japan) and from its relative *Amaranthus*, finding different values among the samples. In addition, Pasko et al.31 reported that quinoa presents higher antioxidant activity than amaranth using different methodologies: ferric reducing/antioxidant potential (FRAP), 2,2′-azinobis(3-ethylbenzothiazoline 6-sulfonate) (ABTS) and 2, 2-diphenyl-1-picryl-hydrazyl (DPPH). Antioxidant activity of quinoa might be of particular interest to medical researchers and needs further attention regarding its utilization as a natural potent antioxidant.10

ANTINUTRITIONAL FACTORS

Several antinutritional substances have been found in quinoa, such as, saponins, phytic acid, tannins and protease inhibitors,34,58 which can have a negative effect on performance and survival of monogastric animals when it is used as the primary dietary energy source.58

Saponins were found to be the primary anti-quality factors associated with quinoa,58 but they have also some interesting biological properties.59 Saponins are natural detergents made of glycosylated secondary metabolites, distributed throughout the plant kingdom; they include a diverse group of compounds characterized by their structure containing a steroidal or triterpenoid aglycone and one or more sugar chains.60 The quinoa is surrounded by an epicarp that contains saponins showing a characteristic bitter or astringent taste.61 Quinoa can be classified in accordance with the content of saponins.21,27,62–64 Stuardo and San Martín63 reported that the content of saponins varies in quinoa between 0.1% and 5%. From the nutritional or pharmacological point of view saponins could also have some value. They can increase membrane permeability, thus enabling use for increasing logical point of view saponins could also have some value. They can increase membrane permeability, thus enabling use for increasing

ISOFLAVONES

Finally, a recent yet unpublished thesis63 showed that quinoa seeds from different origins, including long-distance regions of Chile, show different isoflavone concentrations, particularly daidzein and genistein. These hormones are implicated in plant physiology (protection from pathogens, from UV light and nitrogen-limited soils) and could be recognized by alpha and beta receptors of estrogens in humans. These endoplasmic reticulum-linked receptors are implicated as inhibitors of tyrosine kinase enzymes, and as antagonists of vessel contraction. They also reduce arterial resistance, benefit bone density and stimulate osteoprogerin secretion by osteoblasts, in addition to its antioxidant properties.83

SUMMARY OF QUINOA FUNCTIONAL POTENTIAL FOR HUMAN DIET

Some Leguminosae in combination with some cereals might improve proteic profiles of high-quality foods due to amino acid compensation, a good strategy also used with quinoa food for children in the Andean region. Cerezal et al.74 designed a food for 3- to 5-year-old children, with high amino acid content (35–40% of daily requirements). Nsimba et al.57 used quinoa and amaranth in products such as bread, pastas and baby foods. Lorenz and Coulter45 evaluated quinoa flour extrusion mixed with maize grits to develop snacks with moderate acceptance. Moreover, there is evidence concerning other physiologically active compounds present in quinoa seeds such as tannins17 and betaines.75 Tannins, which are polyphenolic compounds, form complexes with dietary proteins and also with digestive enzymes.79 In addition to proteins, humans require minerals for their normal life processes, particularly essential minerals, those necessary to support adequate growth, reproduction and health throughout the life cycle. Because they cannot be synthesized, minerals are necessarily obtained from the diet, and thus animals require a mineral intake for a long-term maintenance of body mineral reserves.77 Minerals are involved in many important functions in the body, e.g. cofactors of hundreds of enzymatic reactions, bone mineralization, as well as protection of cells and lipids in biological membranes (antioxidant properties). Low intake or reduced bioavailability of minerals may lead to deficiencies, which causes serious impairment of body functions.78 Quinoa content is rich in minerals such as calcium, iron, zinc, magnesium and manganese, which give the grains high value for different target populations: for instance, adults and children benefit from calcium for bones and from iron for blood functions.27,33 Antioxidant properties conferred by vitamin E and ω-3 fatty acids, plus the neuronal activity of cryptophan amino acid and vitamin B complex, can be powerful aids in brain function. Strong effects on protection of stressed neurons given by quinoa consumption in lab rats has recently been demonstrated, with evident effects on neuronal gene expression under stressing conditions, and also on improving spatial memory and promotion of low anxiety in the same animals.79 All these effects should be important in adults as well as in child populations. Besides, zinc helps the immunological system and magnesium is also important during the formation of neuromessengers and neuron modulators. Quinoa also improves some insulin-like forms which are active as growth hormones.80 The low glycemic index makes quinoa good for diabetic patients (low fructose and glucose), as mentioned by Oshodi et al.81 Celiac and lactose-intolerant subjects should also be quinoa consumers because of its gluten-free nature and its rich protein levels, similar to milk casein quality.82
CONCLUSIONS
The outstanding physicochemical, nutritional and functional properties of quinoa have been reviewed. From ancient and historical data to current laboratory scientific evidence, quinoa was cultivated for its nutritional value, and after being abandoned in favor of old-world crops it is now starting to be rediscovered by modern scientific approaches. Bitter seed coat saponins, while probably giving slower speed to quinoa recovery, might now be helpful for its ‘take-off’ among farmers for a broader range of consumers, as such saponins also have important agro-pharmacological and cosmetic industrial uses. From the point of view of vegetarian consumers, quinoa in combination with other cereals might easily replace meat, with a great future in modern, conscient and more ecological food habits. Functional properties given by strongly active compounds like minerals, vitamins, fatty acids and antioxidants make of this small and noble grain a strong contribution to human nutrition, particularly for all cell processes requiring antioxidant protection of membranes, like neuronal activity, with minerals and amino acid contents with potential implications for aiding memory and lowering anxiety under stressful conditions.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge the Research Department at Universidad de La Serena (DIULS), Chile, for providing financial support to the project (DIULS PI07302). In addition, we wish to thank Project Fondecyt 1060281, 1100638, and funding by ANR-IMAS, TWAS-ICGEB and IRSES agencies.

REFERENCES
7 Tagle MB and Planella MT, La quinoa en la zona central de Chile: Supervivencia de una tradición prehispana. Editorial IKU, Santiago, Chile (2002).