Review

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

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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.[1] This strike left two million people without shelter and food supplies.[2] 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* Willd., 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.[3,4] It has been cultivated in this area for the last 5000–7000 years[5,6] 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.[7] 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.[5,7,8] 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.[9] 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.[10] Particularly in Europe a project was approved in 1993 entitled 'Quinoa: a multipurpose crop for the European Community', for agriculture diversification.[11,12]

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

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Figure 1. Quinoa panicules (*Chenopodium quinoa* Willd).

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,[8] as for instance Amarilla de Marangani and Blanca de Junín, two commercial varieties grown in greater proportion in the Andes of southern Peru.[13] Most varieties of quinoa commonly differ in the morphology, phenology and the chemical composition of the tissues.[14]

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.[15]

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).[16]

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.[17] Seed size and color are variable.[18] 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).[19] The classification of quinoa was first made from the color of the plant and fruits. Subsequently, it was based on the morphological

Table 1. Main uses of quinoa

Main uses	Component implied	Plant organ
Foods and drinks	Vitamins	Seeds and leaves
	Proteins	Seeds and leaves
Animal food	Vitamins	Whole plant
	Proteins	Whole plant
Medicine	Immune system	Leaves and seeds
	Skin applications	Leaves and seeds
	Circulatory applications	Leaves and seeds
Repellent	Insects	Leaves and seed coat

FAO.[26]

types of the plant. Despite the wide variation observed, quinoa is considered to be one single species.[16]

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.[16]

The cultivation cycle lasts 8 months in the high Andes but it can be as short as 4 months in arid central Chile.[20] 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.[21] It also seems to have exceptional physiological adaptations for high water use efficiency under stomatal closure[21] besides efficient roots for water capture, as earlier pointed out by Wood.[22] In arid regions the addition of organic matter also increases water use efficiency and grain yields.[21] Strong tolerance has been also demonstrated for other stressing conditions such as salty soils and cold climate.[12,23] Quinoa can be grown on various types of soils, including marginal soils,[8] under a wide range of acid/alkaline conditions (from pH 6.0 to 8.5). The plant is not affected from around $-1\,^{\circ}$C. However, it tolerates high temperatures up to $35\,^{\circ}$C. Quinoa is resistant to freezing temperatures if the frost occurs before flowering. However, if the frost occurs after flowering, significant damage may affect the plant.

As mentioned above, quinoa is a drought-tolerant crop having low water requirements, although yield is significantly affected by irrigation.[24] It is able to develop even in regions where the annual rainfall is in the range of 200–400 mm,[16] but it has been proven that it can be grown in southern Chile with an annual precipitation as high as 3000 mm.[20] Although having good a response in poor soils, quinoa does respond well to nitrogen fertilization. Thus nitrogen significantly increases seed production and protein content.[25]

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 2. Proximate analysis of quinoa (g 100 g^{-1} fresh weight)

	References			
Component	Kozioł[27]	Wright *et al.*[28]	De Bruin[29]	Dini *et al.*[30]
Protein	16.5	16.7	15.6	12.5
Fat	6.3	5.5	7.4	8.5
Ash	3.8	3.2	3.0	3.7
Carbohydrate	69.0	74.7	69.7	60.0
Crude fiber	3.8	10.5	2.9	1.92

Table 3. Essential amino acid profile (g 100 g^{-1} protein)

	References				
Amino acid	Kozioł[27]	Dini *et al.*[30]	Repo-Carrasco *et al.*[33]	Wright *et al.*[28]	González *et al.*[34]
His	3.2	2.0	2.7	3.1	ND
Ile	4.4	7.4	3.4	3.3	ND
Leu	6.6	7.5	6.1	5.8	ND
Met + Cys	4.8	4.5	4.8	2.0[a]	2.4[a]
Phe + Tyr	7.3	7.5	6.2	6.2	ND
Thr	3.8	3.5	3.4	2.5	ND
Val	4.5	6.0	4.2	4.0	ND
Lys	6.1	4.6	5.6	6.1	6.6
Trp	1.2	ND	1.1	ND	1.1

His, histidine; Ile, isoleucine; Leu, leucine; Met + Cys, methionine + cystine; Phe + Tyr, phenylalanine + tyrosine; Thr, threonine; Val, valine; Lys, lysine; Trp, tryptophan.
ND, not detected.
[a] Only methionine reported.

popular among people interested in improving and maintaining their health status by changing dietary habits. The seeds and sprouts are both excellent examples of 'functional food', defined as lowering the risk of various diseases and/or exerting health-promoting effects, in addition to its nutritive value.[31] Most of the recently published papers are focused mainly on studies of typical sprouts such as buckwheat, broccoli, mung bean, and soybean, which are already readily available on the market. The sprouts of amaranth and quinoa are 'new' vegetables, which can be used in vegetarian nutrition and as a common diet too.[31] Today's health-conscious consumers are illustrating a preference towards value-added products. The opportunity to supplement or completely replace common cereal grains (corn, rice and wheat) with a cereal of higher nutritional value (such as quinoa) is inherently beneficial to the public interest.[32] We will review the known composition and nutritional facts reported for quinoa, before describing the potential for functional properties and for human health, particularly for certain consumers (the elderly, children, high-performance athletes, diabetics, celiacs, people who are gluten or lactose intolerant).

Proteins

Protein nutritional quality is determined by the proportions of essential amino acids, which cannot be synthesized by animals and hence must be provided in the diet. If only one of these amino acids is limiting, the others will be broken down and excreted, resulting in poor growth of livestock and humans and loss of nitrogen in the diet. Ten amino acids are strictly essential: lysine, isoleucine, leucine, phenylalanine, tyrosine, threonine, tryptophan, valine, histidine and methionine, all of which are present in quinoa (Table 3), providing it with a similar value to casein, the protein of milk.[33,35] Koziol[27] showed that protein content in quinoa grain ranges from 13.8% to 16.5%, with an average 15%. Wright *et al.*[28] reported a protein content of 14.8% and 15.7% for sweet and bitter quinoa, respectively, from Bolivia. De Bruin[29] studied the protein content of four genotypes of quinoa, reporting a range of 12.9–15.1%.

According to values indicated by FAO/WHO/UNU,[36,37] quinoa protein can supply around 180% of the histidine, 274% of the isoleucine, 338% of the lysine, 212% of the methionine + cysteine, 320% of the phenylalanine + tyrosine, 331% of the threonine, 228% of the tryptophan and 323% of the valine recommended in protein sources for adult nutrition. In addition, the sulfur-containing amino acids cystine, and methionine are found in concentrations that are unusually high compared to other plants,[38] probably due to the type of land (volcanic) where this plant originated. The content of essential amino acids in quinoa (Table 3) is higher than in common cereals.[28,39] Mahoney *et al.*,[40] working with Bolivian quinoa, concluded that protein contained high amounts of lysine and methionine even though there is considerable variation between these varieties in the contents of such amino acids. Dini *et al.*,[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.[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.[42]

Carbohydrates

Starch, the major biopolymeric constituent of plants (grains, seeds and tubers) occurs typically as granular forms of various shapes and sizes.[43] Starch provides the major source of physiological energy in the human diet and accordingly it is classified, in general, as available carbohydrate.[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.*,[33] of which 11% is amylose.[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.[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.[48] Also, its content of D-ribose and D-galactose and maltose would result in a low fructose glycemic index. Repo-Carrasco *et al.*[33] reported for quinoa 1.70 mg 100 g^{-1} of glucose, 0.20 mg 100 g^{-1} of fructose, 2.90 mg 100 g^{-1} of saccharose and 1.40 mg 100 g^{-1} of maltose.

Minerals

Quinoa has a high content of calcium, magnesium, iron, copper and zinc.[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[38]

Table 4. Mineral composition (mg kg^{-1} dry weight)

References	Minerals						
	Ca	P	Mg	Fe	Zn	K	Cu
Kozioł[27]	1487	3837	2496	132	44	9267	51
Repo-Carrasco *et al.*[33]	940	1400	2700	168	48	ND	37
Ruales and Nair[17]	874	5300	260	81	36	12000	10
Bhargava *et al.*[10]	1274	3869	ND	20	48	6967	ND
Konishi *et al.*[50]	863	4110	5020	150	40	7320	ND
Dini *et al.*[30]	275	4244	ND	26	27.5	75	ND
Sanders[52]	565	4689	1760	14	28	11930	2
González *et al.*[34]	1020	1400	ND	105	ND	8225	ND

ND, not detected.

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

Vitamin	References	
	Kozioł[27]	Ruales and Nair[17]
Ascorbic acid (C)	4.0	16.4
α-Tocoferol (E)	5.37	2.6
Thiamin (B_1)	0.38	0.4
Riboflavin (B_2)	0.39	ND
Niacin (B_3)	1.06	ND

ND,not detected.

(Table 4). For instance, Ruales and Nair[39] and Ahamed *et al.*[47] reported that iron, calcium and phosphorus levels are higher than those of maize and barley: iron was 81 mg kg^{-1} and calcium was 874 mg kg^{-1}. It also has about 0.26% of magnesium in comparison to 0.16% of wheat and 0.14% of corn. Schlick and Bubenheim,[38] comparing quinoa from different sources (USA, Peru, Bolivia and Chile), reported that the mineral concentrations for quinoa seem to vary dramatically. This may occur due to the soil type and mineral composition of the region and/or fertilizer application.

With respect to the distribution of minerals within the grain, Konishi *et al.*[50] used scanning electron microscopy with energy-dispersive X-ray detection on seed with and without epicarp, finding that minerals like P, K and Mg were located in the embryo, while Ca and P in the pericarp were associated with pectic compounds of the cell wall. Thus abrasive procedures to remove saponins might cause losses of 40% and 10%, respectively. Sulfur is found uniformly distributed within the embryo. The iron has been reported as highly soluble and thus could be easily available to anemic populations.[51]

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.[53] Table 5 shows the main vitamins found in quinoa. The quinoa is found to be rich in α-carotene and niacin. Ruales and Nair[39] have reported

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

Reference	Fatty acid		
	Oleic	Linoleic	Linolenic
Kozioł[27]	23.3	53.1	6.2
Repo-Carrasco *et al.*[33]	26.0	50.2	4.8
Ruales and Nair[17]	24.8	52.3	3.9

appreciable amounts of thiamin (0.4 mg 100 g^{-1}), folic acid (78.1 mg 100 g^{-1}) and vitamin C (16.4 mg 100 g^{-1}). Kozioł[27] compared the vitamin contents of quinoa with some cereals (rice, barley and wheat) and reported that quinoa contains substantially more riboflavin (B_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_6, 0.61 mg pantothenic acid, 23.5 g folic acid and 7.1 g biotin.[10] Repo-Carrasco *et al.*[33] also reported that quinoa is rich in vitamin A, B_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.[33]

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%).[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.[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.[37] There are two known families of EFAs: omega-3 (ω-3) and omega-6 (ω-6).[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 polyunsaturated fatty acids identified in quinoa; polyunsaturated fatty acids have several positive effects on cardiovascular disease and improved insulin sensitivity.[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,[30] while Ahamed *et al.*[47] 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.[56] Repo-Carrasco *et al.*[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.[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

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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]

Paśko *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, Paśko *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-2-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 saponin concentration and their content depends on the quinoa variety: 'sweet' (free from or containing $<0.11\%$ of free saponins) or 'bitter' (containing $>0.11\%$ of free saponins).[21,27,62–64] Stuardo and San Martin[63] 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 food intake at the intestinal level or even for drug assimilation.[64,65] Other applications include raw materials for production of hormones[66] and immunological adjuvants,[67] and there are also reported to be active ingredients in various natural health products, such as herbal extracts.[68] Stuardo and San Martín,[63] Keukens *et al.*[69] and Armah *et al.*[70] reported antifungal activity of quinoa saponins due to its capacity to associate with steroids of fungal membranes, causing damage to its integrity and pore formation, probably the basis of the novel molluscicide derived from the husks of quinoa, discovered and developed by San Martín *et al.*[71]

Phytic acid is not only present in the outer layers of quinoa, as in the case of rye and wheat,[47] but is also evenly distributed in the endosperm. Phytic acid binds minerals, thereby rendering them unavailable for metabolism.[47,72] Ranges of 10.5–13.5 mg g^{-1} of phytic acid for five different varieties of quinoa were reported by Kozioł.[27]

Protease inhibitors, broadly distributed in nature, are proteins that form very stable complexes with proteolytic enzymes.[73] The concentration of protease inhibitors in quinoa seeds is <50 p.p.m.[47] Ahamed *et al.*[47] and Improta and Kellems[58] reported that quinoa contains small amounts of trypsin inhibitors which are much lower than those in commonly consumed grains and hence do not pose any serious concern.

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 Coulter[45] 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 tannins[17] and betaines.[75] Tannins, which are polyphenolic compounds, form complexes with dietary proteins and also with digestive enzymes.[76] 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 tryptophan 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]

ISOFLAVONES

Finally, a recent yet unpublished thesis[83] 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]

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.

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REFERENCES

1 USGS, United States Geological Survey. [Online]. Available: http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/ [2 March 2010].
2 Legrand C, [Online]. Available: <http://www.lemonde.fr/ameriques/article/2010/03/01/des-millions-de-refugies-au-chili-apres-un-fort-seisme_1312672_3222.html#xtor=EPR-32280229-[NL_Titresdujour]-20100301-[zoneb]&ens_id=1312017> [2 March 2010].
3 Maughan PJ, Kolano BA, Maluszynska ND, Coles ND, Bonifacio A, Rojas J, *et al*, Molecular and cytological characterization of ribosomal RNA genes in *Chenopodium quinoa* and *Chenopodium berlandieri*. *Genome* **49**:825–839 (2006).
4 Christensen SA, Pratt DB, Nelson PT, Stevens MR, Jellen EN, Coleman CE, *et al*, Assessment of genetic diversity in the USDA and CIP-FAO international nursery collections of quinoa (*Chenopodium quinoa* Willd.) using microsatellite markers. *Plant Genet Resour* **5**:82–95 (2007).
5 National Research Council (NRC), *Lost Crops of the Incas: Little Known Plants of the Andes with Promise for Worldwide Cultivation*. National Academy Press, Washington, DC, pp. 148–161 (1989).
6 Mujica A, Izquierdo J and Marathee JP, Origen y descripción de la quinua, in *Quinua (Chenopodium quinoa Willd.): Ancestral cultivo andino, alimento del presente y futuro*, ed. by Mujica A, Jacobsen S-E, Izquierdo J, Marathee J. FAO, UNA-Puno, CIP, Santiago, Chile, pp. 9–29 (2001).
7 Tagle MB and Planella MT, *La Quinoa en la zona central de Chile: Superviviencia de una tradición prehispana*. Editorial IKU, Santiago, Chile (2002).
8 Tapia M, *Cultivos andinos subexplotados y su aporte a la alimentación* (2nd edn). FAO, Oficina Regional para América Latina y el Caribe, Santiago, Chile (1997).
9 Fuentes FF, Martínez EA, Hinrichsen PV, Jellen EN and Maughan PJ, Assessment of genetic diversity patterns in Chilean quinoa (*Chenopodium quinoa* Willd.) germplasm using multiplex fluorescente microsatellite markers. *Conserv Genet* **10**:369–377 (2008).
10 Bhargava A, Shukla S and Ohri D, *Chenopodium quinoa*: an Indian perspective. *Ind Crops Prod* **23**:73–87 (2006).
11 Jacobsen SE, Adaptation of quinoa (*Chenopodium quinoa*) to northern European agriculture: studies on developmental pattern. *Euphytica* **96**:41–48 (1997).
12 Jacobsen SE, Developmental stability of quinoa under European conditions. *Ind Crops Prod* **7**:169–174 (1998).
13 Ormachea E and Quispe D, Evaluación de parasitoides de la 'polilla de la quinua' Eurysacca melanocampta, en el Cusco, in *XXXV Convención Nacional de Entomología*, Arequipa, Perú, 11–14 November (1993).
14 Bertero HD, De La Vega AJ, Correa G, Jacobsen SE and Mujica A, Genotype and genotype-by-environment interaction effects for grain yield and grain size of quinoa (*Chenopodium quinoa* Willd.) as revealed by pattern analysis of international multi-environment trials. *Field Crops Res* **89**:299–318 (2004).
15 Cusack DF, Quinua: grain of the Incas. *Ecologist* **14**:21–31 (1984).
16 Valencia-Chamorro SA, Quinoa, in *Encyclopedia of Food Science and Nutrition*, ed. by Caballero B. Academic Press, Amsterdam, pp. 4895–4902 (2003).
17 Ruales J and Nair BM, Saponins, phytic acid, tannins and protease inhibitors in quinoa (*Chenopodium quinoa* Willd.). *J Sci Food Agric* **54**:211–219 (1993).
18 Mujica A, Andean grains and legumes, in *Neglected Crops: 1492 from a Different Perspective*, ed. by Hernando Bermujo JE, Leon J. FAO, Rome, pp. 131–148 (1994).
19 Risic JC and Galwey NW, The *Chenopodium* grains of the Andes: Inca crops for modern agriculture, in *Advances in Applied Microbiology*, ed. by Coaker TH. Academic Press, London, pp. 145–217 (1984).
20 Martínez EA, Delatorre J and Von Baer I, Quínoa: las potencialidades de un cultivo sub-utilizado en Chile. *Tierra Adentro (INIA)* **75**:24–27 (2007).
21 Martínez EA, Veas E, Jorquera C, San Martín R and Jara P, Re-introduction of *Chenopodium quinoa* Willd. into arid Chile: cultivation of two lowland races under extremely low irrigation. *J Agron Crop Sci* **195**:1–10 (2009).
22 Wood TR, Tale of a food survivor: Quinoa. *East West J* **4**:63–68 (1985).
23 Mujica A, Jacobsen SE and Izquierdo J, Resistencia a factores adversos de la quinua, in *Quinua (Chenopodium quinoa Willd.): Ancestral Cultivo Andino, Alimento del Presente y Futuro*, ed. by Mujica A, Jacobsen S-E, Izquierdo J, Marathee JP. FAO, UNA-Puno, CIP, Santiago, pp. 162–183 (2001).
24 Oelke EA, Putnam DH, Teynor TM and Oplinger ES, *Alternative field crops manual*. University of Wisconsin Cooperative Extension Service, University of Minnesota Extension Service, Centre for Alternative Plant and Animal Products (1992).
25 Thanapornpoonpong SN, Vearaslip S, Pawelzik E and Gorinstein S, Influence of various nitrogen applications on protein and amino acid profiles of amaranth and quinoa. *J Agric Food Chem* **56**:11464–11470 (2008).
26 FAO, Food and Agriculture Organization, Ecocrop Database (2007). [Online]. Available: http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2509 [29 May 2009].
27 Kozioł M, Chemical composition and nutritional evaluation of Quinoa. (*Chenopodium quinoa* Willd). *J Food Comp Anal* **5**:35–68 (1992).
28 Wright KH, Pike OA, Fairbanks DJ and Huber SC, Composition of *Atriplex hortensis*, sweet and bitter *Chenopodium quinoa* seeds. *Food Chem Toxicol* **67**:1383–1385 (2002).
29 De Bruin A, Investigation of the food value of quinoa and cañihua seed. *J Food Sci* **29**:872–876 (1963).
30 Dini A, Rastrelli L, Saturnino P and Schettino O, A compositional study of *Chenopodium quinoa* seeds. *Nahrung* **36**:400–404 (1992).
31 Paśko P, Bartoń H, Zagrodzki P, Gorinstein S, Folta M and Zachwieja Z, Anthocyanins, total polyphenols and antioxidant activity in amaranth and quinoa seeds and sprouts during their growth. *Food Chem* **115**:994–998 (2009).
32 Brady K, Ho C, Rosen R, Sang S and Karwe M, Effects of processing on the nutraceutical profile of quinoa. *Food Chem* **100**:1209–1216 (2007).
33 Repo-Carrasco R, Espinoza C and Jacobsen SE, Nutritional value and use of the Andean crops quinoa (*Chenopodium quinoa*) and kañiwa (*Chenopodium pallidicaule*). *Food Rev Int* **19**:179–189 (2003).
34 González JA, Roldán A, Gallardo M, Escudero T and Prado FE, Quantitative determinations of chemical compounds with nutritional value from inca crops: *Chenopodium quinoa* ('quinoa'). *Plant Foods Hum Nutr* **39**:331–337 (1989).

35 Ridout CL, Price KP, Dupont MS, Parker ML and Fenwiclk GR, Quinoa saponins: analysis and preliminary investigation into the effects of reduction by processing. *J Sci Food Agric* **54**:165–176 (1991).
36 FAO/WHO/UNU, Food and Agriculture Organization of the United States/World Health Organization/United Nations University, *Energy and protein requirements*. Report of a joint FAO/WHO/UNU meeting. World Health Organization, Geneva (1985).
37 Abugoch LE, Quinoa (*Chenopodium quinoa* Willd.): composition, chemistry, nutritional, and functional properties. *Adv Food Nutr Res* **58**:1–31 (2009).
38 Schlick G and Bubenheim DL, Quinoa: candidate crop for NASA's controlled ecological life support systems, in *Progress in New Crops*, ed. by Janick J. ASHS Press, Arlington, VA, pp. 632–640 (1996).
39 Ruales J and Nair BM, Properties of starch and dietary fibre in raw and processed quinoa (*Chenopodium quinoa*, Willd.) seeds. *Plant Foods Hum Nutr* **45**:223–246 (1994).
40 Mahoney AW, Lopez JG and Hendricks DG, An evaluation of the protein quality of quinoa. *J Agric Food Chem* **23**:190–193 (1975).
41 Aluko RE and Monu E, Functional and bioactive properties of quinoa seed protein hydrolysates. *J Food Sci* **68**:1254–1258 (2003).
42 Bhargava A, Rana TS, Shukla S and Ohri D, Seed protein electrophoresis of some cultivated and wild species of *Chenopodium*. *Biol Plant* **49**:505–511 (2005).
43 Tharanathan RN, Starch: the polysaccharide of high abundance and usefulness. *J Sci Ind Res* **54**:452–458 (1995).
44 Tharanathan RN and Mahadevamma S, Grain legumes: a boom to human nutrition. *Trends Food Sci Technol* **14**:507–518 (2003).
45 Lorenz K and Coulter L, Quinoa flour in baked products. *Plant Foods Hum Nutr* **41**:213–223 (1991).
46 Jian YQ and Kuhn M, Characterization of *Amaranthus cruentus* and *Chenopodium quinoa* starch. *Starch–Stärke* **51**:116–120 (1999).
47 Ahamed NT, Singhal RS, Kulkarni PR and Mohinder P, A lesser-known grain, *Chenopodium quinoa*: review of the chemical composition of its edible parts. *Food Nutr Bull* **19**:61–70 (1998).
48 Ogunbengle HN, Nutritional evaluation and functional properties of quinoa (*Chenopodium quinoa*) flour. *Int J Food Sci Nutr* **54**:153–158 (2003).
49 Dini I, Tenore GD and Dini A, Nutritional and antinutritional composition of Kancolla seeds: an interesting and underexploited andine food plant. *Food Chem* **92**:125–132 (2005).
50 Konishi Y, Hirano S, Tsuboi H and Wada M, Distribution of minerals in quinoa (*Chenopodium quinoa* Willd.) seeds. *Biosci Biotechnol Biochem* **68**:231–234 (2004).
51 Valencia S, Svanberg U, Sandberg AS and Ruales J, Processing of quinoa (*Chenopodium quinoa* Willd.): effects on *in vitro* iron availability and phytate hydrolysis. *Int J Food Sci Nutr* **50**:203–211 (1999).
52 Sanders M, *Estudio del secado industrial de la quinoa (Chenopodium quinoa Willd.) cultivada en Chile: efecto de la temperatura sobre su composición*. Tesis de Pregrado. Departament of Food Engineering, Universidad de La Serena, Chile (2009).
53 Zeng X, Cheng K-W, Jiang Y, Lin Z-X, Shi J-J, Ou S-Y, *et al*, Inhibition of acrylamide formation by vitamins in model reactions and fried potato strips. *Food Chem* **116**:34–39 (2009).
54 Insel P, Turner RE and Ross D, *Discovering Nutrition*. American Dietetic Association, Jones & Bartlett, Boston, MA (2003).
55 Moyad MA, An introduction to dietary/supplemental omega-3 fatty acids for general health and prevention. Part I. *Urol Oncol* **23**:28–35 (2005).
56 Ng SC, Anderson A, Coker J and Ondrus M, Characterization of lipid oxidation products in quinoa (*Chenopodium quinoa*). *Food Chem* **101**:185–192 (2007).
57 Nsimba RY, Kikuzaki H and Konishi Y, Antioxidant activity of various extracts fractions of *Chenopodium quinoa* and *Amaranthus* spp. seeds. *Food Chem* **106**:760–766 (2008).
58 Improta F and Kellems RO, Comparison of raw, washed and polished quinoa (*Chenopodium quinoa* Willd.) to wheat, sorghum or maize based diets on growth and survival of broiler chicks. [Online]. *Livest Res Rural Dev* **13** (2001). Available: http://www.cipav.org.co/lrrd/lrrd13/1/impr131.htm [29 May 2009].
59 Sparg SG, Light ME and Van Staden J, Biological activities and distribution of plant saponins. *J Ethnopharmacol* **94**:219–243 (2004).
60 Güçlü-Üstündag Ö and Mazza G, Saponins: properties, applications and processing. *Crit Rev Food Sci Nutr* **47**:231–258 (2007).
61 Tarade KM, Singhal RS, Jayram RV and Pandit AB, Kinetics of degradation of saponins in soybean flour (*Glycine max*) during food processing. *J Food Eng* **76**:440–445 (2006).
62 Soliz-Guerrero JB, Jasso de Rodríguez D, Rodríguez-García R, Angulo-Sánchez JL and Méndez-Padilla G, *Quinoa saponins*: concentration and composition analysis, in *Trends in New Crops and New Uses*, ed. by Janick J and Whipkey A. ASHS Press, Alexandria, VA, pp. 110–114 (2002).
63 Stuardo M and San Martín R, Antifungal properties of quinoa (*Chenopodium quinoa* Willd.) alkali treated saponins against *Botrytis cinerea*. *Ind Crops Prod* **27**:296–302 (2008).
64 Gee JM, Price KR, Ridout CL, Wortley GM, Hurrel RF and Johnson IT, Saponins of quinoa (*Chenopodium quinoa*): effect of processing on their abundance in quinoa products and their biological effects on intestinal mucosal tissue. *J Sci Food Agric* **63**:201–209 (1993).
65 Oakenfull D and Sidhu G, Could saponins be a useful treatment for hypercholesterolaemia? *Eur J Clin Nutr* **44**:79–88 (1990).
66 Blunden G, Culling C and Jewers K, Steroidal sapogenins: a review of actual and potential plant sources. *Trop Sci* **17**:139–154 (1975).
67 Kensil CR, Mo AX and Truneh A, Current vaccine adjuvants: an overview of a diverse class. *Frontiers Biosci* **9**:2972–2988 (2004).
68 Balandrin MF, Commercial utilization of plant-derived saponins: an overview of medicinal, pharmaceutical, and industrial applications, in *Saponins Used in Traditional Medicine*, ed. by Waller GR and Yamasaki K. Plenum Press, New York, pp. 1–14 (1996).
69 Keukens AJ, De Vrije T, Van den Boom C, De Waard P, Plasman HH, Thiel F, *et al*, Molecular basis of glycoalkaloid induced membrane disruption. *Biochem Biophys Acta* **1240**:216–228 (1995).
70 Armah CN, Mackie AR, Roy C, Price K, Osbourn AE, Bowyer P, *et al*, The membrane permeabilizing effect of avenacin A-1 involves the reorganization of bilayer cholesterol. *Biophys J* **76**:281–290 (1999).
71 San Martín R, Ndjoko K and Hostettmann K, Novel molluscicide against *Pomacea canaliculata* based on quinoa (*Chenopodium quinoa*) saponins. *Crop Prot* **27**:310–319 (2008).
72 Khattak AB, Zeb A, Bibi N, Khalil SA and Khattak MS, Influence of germination techniques on phytic acid and polyphenols content of chickpea (*Cicer arietinum* L.) sprouts. *Food Chem* **104**:1074–1079 (2007).
73 Aguirre C, Váldez-Rodríguez S, Mendoza-Hernández G, Rojo-Domínguez A and Blanco-Labra A, A novel 8.7 kDA protease inhibitor from chan seeds (*Hyptis suaveolens* L.) inhibits proteases from the larger grain borer *Prostephanus truncatus* (Coleoptera: Bostrichidae). *Comp Biochem Physiol* Part B **138**:81–89 (2004).
74 Cerezal P, Carrasco A, Pinto K, Romero N and Arcos R, Suplemento alimenticio de alto contenido protéico para niños de 2–5 años, desarrollo de la formulación y aceptabilidad. *Interciencia* **32**:857–864 (2007).
75 Dini I, Tenore GC, Trimarco E and Dini A, Two novel betaine derivatives from Kancolla seeds (Chenopodiaceae). *Food Chem* **98**:209–213 (2006).
76 Singh U and Eggum BO, Factors, affecting the quality of pigeonpea (*Cajanus cajan* L.). *Plant Foods Hum Nutr* **34**:273–283 (1984).
77 McDowell LR, *Minerals in Animal and Human Nutrition* (2nd edn). Elsevier, Amsterdam (2003).
78 Schlenker ED and Williams SR, *Essentials of Nutrition and Diet Therapy*. Elsevier, Amsterdam (2003).
79 Muñoz-Llancao P, Martínez EA, Wyneken U and Dagnino-Subiabre A, Pseudo cereal quinoa improves memory and decreases anxiety of stressed rats: behavioral and molecular approaches, in *I IBRO/LARC Congress of Neurosciences of Latin America, Caribbean and Iberian Peninsula*, Búzios, Brazil, 1–4 September (2008).
80 Ruales J, de Grijalva Y, Lopez-Jaramillo P and Nair BM, The nutritional quality of an infant food from quinoa and its effect on the plasma level of insulin-like growth factor-1 (IGF-1) in undernourished children. *Int J Food Sci Nutr* **53**:143–154 (2002).
81 Oshodi AA, Ogungbenle HN and Oladimeji MO, Chemical composition, nutritionally valuable minerals and functional properties of beniseed (*Sesamum radiatum*), pearl millet (*Pennisetum typhoides*) and quinoa (*Chenopodium quinoa*) flours. *Int J Food Sci Nutr* **50**:325–331 (1999).
82 Herencia LI, Alía MJ, González A and Urbano P, Cultivo de la quinoa (*Chenopodium Quinoa* Willd.) en la región Centro. [The culture of quinoa in the central region]. *Vida Rural* **VI**:28–33 (1999).
83 Martínez AM, *Contenido de daidzeina y genisteina en ecotipos de semillas de quínoa (Chenopodium quinoa Willd.)*. Thesis, Chemistry and Pharmacy, Universidad de Valparaíso, Chile (2008).

