Nutritional and biological value of quinoa (*Chenopodium quinoa* Willd.)

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ABSTRACT

Quinoa (*Chenopodium quinoa* Willd.) is a pseudocereal traditionally consumed by Andean cultures that is attracting attention worldwide as a functional food. Because of its tolerance to extreme environmental conditions and its nutritional and biological properties, quinoa has been defined as "one of the grains of the 21st century". In addition to its high content in protein, lipids, fiber, vitamins, and minerals, and its excellent balance of essential amino acids, quinoa has been found to contain numerous phytochemicals including saponins, phytosterols, phytoecdysteroids, phenolics and bioactive peptides. These compounds may exert beneficial effects on metabolic, cardiovascular, and gastrointestinal health. This review summarizes the nutritional and functional role of quinoa emphasizing on the evidence demonstrated by animal and clinical studies.

1. INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd., Amaranthaceae) is a grain-like food crop traditionally used to provide nutrition and sustenance to Andean indigenous cultures for centuries. Quinoa is mainly grown in Peru, Bolivia, Ecuador, Argentina, Chile, and Colombia, although in the last years, it has been introduced in Europe, North America, and Africa with high yields [1]. The quinoa consumption in high-income countries is increasing although is still low compared with the main producer countries of this plant. Thus, quinoa annual consumption in Bolivia and Peru was of 2.37 kg/person and 1.15 kg/person, respectively, whereas the consumption was of 0.03 kg/person in the US [2]. This plant does not belong to the Gramineae family but it produces seeds that can be milled into flour and used as a cereal crop, thus it is habitually referred to as a pseudo-cereal. A number of toasted and baked goods are produced from quinoa flour, such as bread, cookies, biscuits, noodles, pasta, and pancakes, among others [3]. Moreover, quinoa seeds can be fermented to make beer, or a traditional ceremonial alcoholic beverage from South America called “chicha” [4]. Quinoa leaves are eaten similarly to spinach [5], and the germinated quinoa seedlings (quinoa sprouts) are incorporated in salads [6]. The whole plant has been also used as a rich nutritional source to feed livestock, including cattle, pigs, and poultry [3].

Because of its stress-tolerant characteristics and its nutritional and biological properties, quinoa has been described, together Amaranth, as “one of the grains of the 21st century” [7]. Quinoa plant is cold, salt, and drought tolerant, and it can be cultivated in high altitudes in the mountain areas. Moreover, recent investigations have focused on the chemical constituents and therapeutic properties of quinoa that is rapidly gaining recognition as a functional food and nutraceutical [8]. The Food and Agriculture Organization of the United Nations (FAO) launched the International Year of Quinoa in

2013 to promote the production, preservation, and consumption of this crop [9]. This review will summarize the nutritional and biological properties of quinoa emphasizing on the animal and clinical studies performed to demonstrate the health benefits of this crop.

2. NUTRITIONAL PROPERTIES OF QUINOA

Table 1 shows a comparison of the nutritional values of quinoa in relation to rice and wheat, considered as some of the most crucial foods worldwide in both human and animal diets. Quinoa's superiority over these and other grains (rye, barley, and oat, among others) results from its richer protein, lipid, and ash content. Protein content (expressed as g/100 g edible matter) of quinoa seeds is ranged between 13.1% and 16.7%. These values are higher than those of rice, barley, corn, and rye, and close to that of wheat [10]. Albumins and globulins represent the major storage quinoa proteins, with percentages of 35% and 37%, respectively. However, prolamins are present in low concentrations [1]. In addition to their high quantity, quinoa proteins are accepted as high-quality protein because of their balanced pattern of essential amino acids (Table 1). All essential amino acids are present in quinoa protein, meeting amino acid requirements suggested by FAO/WHO/UNU for adults [11]. Quinoa protein presents high content in lysine (ranged from 2.4 to 7.8 g/100 g protein), methionine (0.3-9.1 g/100 g protein), and threonine (2.1-8.9 g/100 g protein) that are the limiting amino acids in conventional cereals, such as wheat and maize [12]. The carbohydrate content of quinoa seed is similar to that of wheat and rice. Starch is the major carbohydrate component constituting 32%-69% of it [1]. Total dietary fiber in quinoa (7.0-11.7 g/100 g edible matter) is near that of cereals such as wheat, while soluble fiber content is ranged from 1.3-6.1 g/100 g edible matter. Individual sugars represent 3% of quinoa

seeds, and are mostly maltose, D-galactose and D-ribose in addition to low levels of fructose and glucose [1]. Besides its high content and good biological quality of their proteins, quinoa seed has an interesting lipid composition of about 5.5-7.4 g/100 g edible matter (Table 1), higher than wheat (1.7 g/100 g edible matter) and rice (0.7 g/100 g edible matter), making quinoa be accepted as an alternative oilseed seed [13]. Palmitic acid is the major saturated fatty acid found in quinoa, constituting 10% of total fatty acids, while unsaturated fatty acids oleic (19.7%-29.5%), linoleic (49.0%-56.4%), and alpha-linolenic (8.7%-11.7%) acids represent 88% of the total fatty acid amount of quinoa seeds, in a similar way to soybean lipid composition [14]. Fatty acids of cell membranes are well protected against damage caused by free radicals by the presence of vitamin E at higher concentration than that of wheat [1, 15]. The levels of other vitamins such as riboflavin (B_2), pyridoxine (B_6), and folic acid are also higher than those of most other grains like wheat, rice, barley, and corn. Pyridoxine and folic acid levels in 100 g of quinoa are reported to meet adults' daily requirements while riboflavin meets 80% of children's and 40% of adults' needs [1]. High vitamin C levels have been also determined in quinoa seeds ranged from 4.0 to 16.4 mg/100 g dry matter (Table 1). However, the thiamin content is lower than that of oat and barley [13]. The mineral content of quinoa is also of great importance. The seeds have high content of calcium, magnesium, iron, copper, and zinc. Many of these minerals are present in higher concentrations to those found in common grains. Moreover, calcium, magnesium, and potassium are found in quinoa in bioavailable forms, thus their contents are considered to be adequate for a balanced diet [8, 14].

3. FUNCTIONAL POTENTIAL OF QUINOA FOR HUMAN HEALTH

In addition to its high nutritional value and gluten-free attribute, quinoa has been reported to exert beneficial effects on high-risk group consumers, such as children, the elderly, lactose intolerant, and people with anemia, diabetes, obesity, dyslipidemia, and celiac disease. These benefits have been linked with the content of protein, fiber, vitamins and minerals, fatty acids, and especially with the presence of a plethora of phytochemicals that provide quinoa a remarkable advantage over other grains in terms of human nutrition and health [13]. The bioactive compounds identified in quinoa and their reported biological activities are shown in Figure 1. Quinoa's outer seed coat is rich in bitter saponins that interfere with its palatability and digestibility making needed their removal before seed consumption. Despite their unpalatable characteristics, a wide range of biological activities have been described for saponins, including antifungal, antiviral, anticancer, hypocholesterolemic, hypoglycemic, antithrombotic, diuretic, and anti-inflammatory activities [18]. The total quinoa saponin fraction has been reported to slightly inhibit the growth of *Candida albicans* [19]. The activity of this fraction against the mycelia growth of *Botrytis cinerea* was improved by alkali treatment, probably due to the formation of more hydrophobic saponin derivatives with higher affinity with the sterols present in cell membranes [20]. Madl and co-workers identified, by nano-HPLC electrospray ionization multi-stage mass spectrometry, 87 triterpene saponins and five novel triterpene aglycones [21]. More recently, Kuljanabhagavad and co-workers identified 20 triterpene saponins from different parts of quinoa plant evaluating their cytotoxic activity in cervix adenocarcinoma HeLa cells [22]. Moreover, a saponin-rich quinoa seed extract has been found to inhibit the release of pro-inflammatory cytokines, and to decrease the production of nitric oxide in lipopolysaccharide-stimulated RAW 264.7 macrophages [23]. The ability of quinoa saponins to affect differentiation of 3T3-

144 L1 preadipocytes and therefore, suppress adipogenesis has also been investigated [24].
145 Phytosterols are lipophilic compounds structurally similar to cholesterol. Due to this
146 similarity, they compete for cholesterol's intestinal absorption and reduce atherogenic
147 lipoprotein production in the intestines and liver, thus exerting reduction of serum
148 cholesterol levels [25]. In addition, antioxidant, anti-inflammatory, and anticancer
149 activities have been described for phytoesterols [26]. These authors found that quinoa
150 contains higher content of phytoesterols than those in cereals such as barley, rye and
151 corn, with β-sitosterol (63.7 mg/100 g), campesterol (15.6 mg/100 g), and stigmasterol
152 (3.2 mg/100 g) as the predominant components.

153 One of the main activities demonstrated for quinoa seeds is the antioxidant
154 activity that has been associated with their high content of phenolic compounds [27].
155 More than 20 phenolic compounds have been found in either free or conjugated forms
156 (liberated by alkaline, acid, and/or enzymatic hydrolysis). Mostly, they are phenolic
157 acids consisting of vanillic and ferulic acids, and their derivatives as well as the
158 flavonoids quercetin, kaempferol, and their glycosides [28, 29]. In addition to their
159 antioxidant properties, these quinoa components have been reported to exert α-
160 glucosidase and pancreatic lipase inhibitory activity [29]. Phytoecdysteroids are
161 polyhydroxylated steroids implicated in plant defense because of their structural
162 relationship with insect molting hormones. Moreover, a wide range of health benefits
163 have been demonstrated for these components, including anabolic, performance
164 enhancing, anti-osteoporotic, anti-diabetic, anti-obesity, and wound healing properties
165 [30]. Quinoa is one of the richest edible sources of phytoecdysteroids, with a content
166 ranged from 138-570 μg/g and 13 different phytoecdysteroid types. Among them, the
167 most common is 20-hydroxyecdysone (20HE) that constitutes 62-90% of total quinoa

phytoecdysteroids [18]. A 20HE-enriched extract obtained from quinoa was demonstrated to reduce fasting blood glucose in obese, hyperglycemic mice [30].

In addition to their nutritional properties, quinoa proteins may exert biological properties. Takao and co-workers reported cholesterol-lowering effects of a quinoa protein-enriched fraction in mice [31]. Moreover, enzymatic hydrolysis has been described as a suitable strategy to release bioactive peptides from quinoa proteins. Aluko and Monu studied the functional (foaming) and biological (antioxidant and angiotensin-converting enzyme inhibitory) properties of an alcalase hydrolyzate of quinoa proteins [32]. Recently, papain hydrolyzates have also been found to inhibit dipeptidyl peptidase IV and to exert antioxidant properties, making them a promising functional ingredient with serum glucose lowering properties [33]. However, the sequences of bioactive peptides have not been identified yet.

Although many quinoa components have been described to contribute on the beneficial effects on human health, to date, the evidence of these benefits demonstrated in both animals and humans is still limited. In a study inquiring the effects on lipid profile and glucose levels in male Wistar rats fed a fructose-enriched diet, it was demonstrated the ability of quinoa seeds to reduce serum total cholesterol, low density lipoproteins (LDL), triglycerides and glucose levels. Also, quinoa added to the diet was shown to inhibit the negative effects of fructose on high density lipoproteins (HDL) levels [34]. In another study, quinoa supplementation in diet administered to oxidative stress-induced rats reduced malondialdehyde levels in plasma and increased antioxidant enzymes activities [35]. These results indicate that quinoa seeds can protect animals from oxidative status by increasing their antioxidant capacity and reducing lipid peroxidation in plasma and different tissues. Foucault and co-workers investigated the potential role of quinoa to prevent diet-induced obesity in mice. Administration of

20HE-enriched quinoa extract to animals fed a high fat diet for 3 weeks resulted in the reduction of the development of adipose tissue in mice without changes in body weight gain. This adipose tissue-specific effect was associated to the down-regulation of expression of genes involved in lipid storage [36]. Few human trials have been conducted to evaluate the benefits of quinoa consumption (Table 2). Administration, twice a day, of 100 g quinoa in quinoa-added baby foods to 50-65 month old boys in low-income families in Ecuador for 15 days significantly augmented the plasma insulin-like growth factor (IGF-1) levels, when compared to the control group. Thus, it was indicated that baby food with quinoa provided sufficient protein and other essential nutritional elements capable to prevent malnutrition among kids [37]. Moreover, supplementation of diet with quinoa has been demonstrated to prevent cardiovascular disorders in healthy people [38] as well as to modulate metabolic parameters in postmenopausal overweight women [39]. Quinoa was administered to celiac patients in order to evaluate the safety of its consumption as a gluten-free alternative to cereal grains [40]. This study found, after 6 weeks consumption of 50 g quinoa daily, an improvement in gastrointestinal parameters and small decreases in total cholesterol, LDL, HDL and triglycerides levels.

CONCLUSIONS

Quinoa is a pseudocereal with an important tradition and notable environmental tolerance, in addition to its high nutritional value. It has been recently reported that one serving of quinoa (about 40 g) meets a significant part of daily recommendations (RDA) for essential nutrients, mainly vitamins, minerals and essential amino acids. Moreover, a plethora of bioactives have been identified in this crop including saponins, phenolic compounds, phytosterols, phytoecdysteroids, and bioactive peptides. These compounds

exert positive effects on different body systems helping to promote human health and to reduce risk of different chronic disorders. However, to date, few data demonstrating these health benefits are available, thus further research, including additional human clinical trials, would be needed to understand the biological properties of quinoa emphasizing on the phytochemicals' bioavailability, mechanisms of action, and interactions.

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* Article demonstrating the safety of quinoa consumption by celiac patients as well as its health benefits.

FIGURE CAPTIONS

Figure 1. Bioactive compounds and biological activities described for quinoa (*Chenopodium quinoa* Willd.).