Processing technologies and health benefits of quinoa

M Naga Sai Srujana, B Anila Kumari, W Jessie Suneetha and P Prathyusha

Abstract

Quinoa (Chenopodium quinoa) Wild) is a stress-tolerant pseudo cereal cultivated along the Andes for the last 7000 years, challenging highly different environmental conditions with Peru and Bolivia being the main producers. The edible seeds of quinoa are small, round and flat. Seed colors can range from white to grey and black, or can be yellow and red. Because of its high nutritional characteristics, United Nations General Assembly has therefore declared 2013 as the “International Year of Quinoa. Quinoa is a rich source of protein (12-16.5%) with protein quality equivalent to that of casein. In addition, this “wonder grain” is gluten free, rich in bioactive compounds like antioxidants, polyphenols, flavonoids, vitamins and minerals that imparts various health benefiting characteristics to this grain. Human health and food security have become increasingly important with the advents of climate change, accelerated human population growth, rise of metabolic disease, and increasing median age of the population. About 1 in 8 individuals are suffering from chronic undernourishment, while diabetes, obesity, and other metabolic disorders resulting in a mounting prevalence of age-related disorders such as fragility, cardiovascular diseases, and osteoporosis. Functional products prepared with different processing techniques such as quinoa cereal bar, quinoa flakes, quinoa pasta, have been known to have various health benefits and to be effective in cases of obesity, cardiovascular diseases, hypertension, and celiac disease. Grain processing techniques like soaking, germination and malting, are known to improve the nutrient content and decrease the antinutrients in quinoa grain.

Keywords: food security, pseudo cereals, quinoa, breakfast cereals, antioxidant properties of quinoa

Introduction

Globalization of agriculture and consequently its industrialization seem inexorable with negative side effects being felt throughout India resulting in biased technological development of some high demanding plant species and monoculture production with reduced genetic diversity in agriculture. As a consequence, Indian food security has become increasingly dependent on only a handful of crops (Izdajatelj, 2010) [21]. The narrowing of the number of crops upon which global food security and economic growth depend has placed the future supply of food and rural incomes at risk. The mentioned facts with profound environmental consequences and concern for loss of crop varieties stimulate organizations and scientists worldwide in retrieving, researching and disseminating the knowledge in production and utilization of neglected, disregarded, underexploited and new plant species, or so called alternative crops. Alternative crops plant species are used traditionally for food, fiber, fodder, oil or medicinal properties. Those are an under-exploited potential crop to contribute to food security, nutrition, health, income generation and environmental services (Hafele and Sassin, 1979) [20].

Pseudocereals are defined as fruits or seeds of non-grass species that are consumed in very similar way as cereals having nutritive value very much competitive to conventional crop, in most cases even better. Quinoa is a pseudo cereal belongs to (Chenopodiaceae) family. Quinoa fruits are achenes, comprised of a single seed enclosed by an outer pericarp (FAO 2011) [13]. Quinoa has been traditionally used by several indigenous peoples of South America (Bhargava and Srivastava 2013) [2]. The seeds have been consumed similarly to rice, prepared in soup, puffed to make breakfast cereal, or ground to flour to produce toasted and baked goods (Cookies, breads, biscuits, noodles, flakes, tortillas, pancakes) (Bhargava et al., 2006) [1]. Quinoa leaves have also been eaten similarly to spinach (Oelke et al., 2012) [32] and the germinated quinoa that is quinoa sprouts have been incorporated in salads (Schlick and Bubenheim. 1996) [43].
Quinoa seeds can be fermented to make beer, the traditional alcoholic beverage from South America called “chicha” (FAO 2011)[13]. The edible seeds of quinoa are small, round and flat. Seed colors can range from white to grey and black, or can be yellow and red. It is consumed as breakfast food as well as staple food similar to maize and potato (Nowak et al. 2015)[31].

**Nutritional composition:** Quinoa contains from 2% to 10% fat. Quinoa is a rich source of essential fatty acids such as linolenic (18:2n-6; 52%) and linoleic (18:3n-6; 40%) (Jancurová et al. 2009)[23]. Quinoa has a similar amino acid composition as rice with higher contents in especially lysine (4.8 g/100 g protein and threonine (3.7 g/100 g protein), which are in general the limiting amino acids in conventional cereals like wheat and maize (Dini et al. 2004)[10]. Zevallos et al., 2012[30] reported that certain quinoa cultivars have celiactoxic epitopes (location on an antigen that interacts with antibodies) that can activate immune responses in some patients with celiac disease. Quinoa is considered gluten-free grain because it contains very little or no prolamin (James, 2009)[22].

**Quinoa leaves and seeds (Graf et al. 2015)[19]**

![Fig 1: Seeds and Quinoa leaves](image)

Quinoa grains based amount of saponins, the grains were classified as bitter. (Nickel et al. 2016)[30]. Washing caused a reduction in the antinutritional compounds, but the levels remained unchanged after cooking (with and without) pressure and toasting. An abrasion degree of 30% was necessary to obtain sweet quinoa with total saponin content lower than 110 mg/100 g (Gómez-Caravaca et al., 2014)[18].

Vitamin C, total Polyphenols and antioxidant activity in raw, domestically processed and industrially processed quinoa has been given in Table 1. (Kaur et al., 2016)[16]. Antioxidant activity and phenolic content have been reported to be greatly affected by domestic processing (Dini et al., 2010)[9].

**Table 1: Effect of processing on vitamin C, TPC and TFC content of quinoa**

<table>
<thead>
<tr>
<th>Processing</th>
<th>Vitamin C</th>
<th>TPC</th>
<th>TFC</th>
</tr>
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<tbody>
<tr>
<td>Raw quinoa</td>
<td>13.43</td>
<td>43.2</td>
<td>11.4</td>
</tr>
<tr>
<td>Soaked</td>
<td>15.09</td>
<td>31.1</td>
<td>7.2</td>
</tr>
<tr>
<td>Germinated</td>
<td>19.38</td>
<td>101.2</td>
<td>18.02</td>
</tr>
<tr>
<td>Industrially processed</td>
<td>9.45</td>
<td>34.6</td>
<td>5.80</td>
</tr>
</tbody>
</table>

Germination: Soaked for 12hrs at 20°C in a BOD for 72 hours (Carciochi, 2014)[16].

**Processing techniques:** Post harvesting and prior to marketing, grains undergo industrial processing, mainly the process of dehulling or decortications, to remove the outer layers of the grain. Dehulling is known to improve grain quality by lowering the content of antinutrients and enhancing the sensory parameters, hence the acceptance and palatability of the grain. Despite these benefits of dehulling, it reported to cause loss of nutrients from grains. Thus, to minimize loss nutrients and increase bioavailability of nutrients, researchers recommend use of common traditional domestic processing methods for grains (Table 2). Soaking and germination are the commonly used methods for domestic processing of seed.

Antioxidant activity and phenolic content have been reported to be greatly affected by domestic processing (Table 1).

Germination of quinoa results in oleic acid increased, but linoleic acid decreased in NL (non polar lipids), GL and PL. The ratio of saturated, monounsaturated and polyunsaturated fatty acids of NL, and PL approached 3: 4: 3. After 72 hr germination, the ratio of Omega3/6 became 0.25 in GL (glycolipids) (Park and Naofumi, 2004)[33]. The tannin and phytate contents could not be detected after steeping and germination (Kanensi, et al., 2011)[25]. Germination resulted in a 2 fold increase in antioxidant activity after 3 days of germination, the amounts phenolic acids and flavonoids increased 8.57 fold, and 4.4 fold respectively. (Carciochi, et al., 2013)[5]. Germination and subsequent oven-drying was shown to be a good process to improve the phenolic content and antioxidant activity of quinoa seed and can be used in functional food formulations. These germinated products contain essential fatty acids that play an important roles in brain development, insulin sensitivity, prostaglandin metabolism, a lower ratio of omega-6: omega-3 fatty acids that helps in cardiovascular health, immunity, inflammation, and autoimmune diseases (Galvez et al., 2010)[16].

Fermentation was carried out naturally by the microorganisms present in the seeds or by inoculation with two *Saccharomyces cerevisiae* strains (used for baking and brewing) there was decreased content of ascorbic acid and tocopherol content and the phenolic compounds and antioxidant capacity were improved. (Carciochi, et al., 2016)[4].

Malting with a moderate thermal treatment is considered an effective process to enrich antioxidants in quinoa grains for their further use as functional ingredient in the production of gluten-free foods and beverages (Carciochi, et al., 2016)[4]. Dehydration of quinoa between 70 and 80°C showed an
increase in vitamin E content and the antioxidant capacity was also increased on dehydration at 40, 50 and 80 °C due to temperature/drying time equivalent processes. The dehydration of quinoa led to reductions of 10% in proteins, 12% in fat and 27% in both fiber and ash content (Miranda et al., 2010) [28].

The heat application to quinoa has shown reduction of anti nutritional factors in Chenopodium quinoa seeds (Silva et al., 2015) [45]. Heat processing is required for complete digestion of food proteins. These processes significantly affect the protein structures, and consequently, their resistance to digestion.

Extrusion processing is used to make extruded ready-to-eat (RTE) breakfast cereal from quinoa, fortified with cranberry concentrate, the extrudates contain higher phenolic values which may be due to the formation of maillard products at higher barrel temperatures and maximum anthocyanins content of 9.63 mg / kg d.m at 140 °C (Chandran, 2015) [8]. Extrusion results in inactivation of antinutrients, destruction of aflatoxins and increasing the digestibility of fiber (Saalia and Phillips, 2011) [40]. Extrusion results in transformation of insoluble dietary fiber to the soluble dietary form in addition to the formation of resistant starch and enzyme resistant glucans through the process of transglycosidation (Repo-Carrasco et al., 2009) [36].

Higher extrusion temperatures in the extrudates of quinoa caused oxidation of unsaturated fatty acids resulting in decreased content of unsaturated fatty acids and inactivation of antinutrients such as lectin and antityrosin inhibitors resulting in the increase of protein digestibility (Chandran, 2015) [8].

Nutritionally improved, gluten-free spaghetti (NIS) with broad bean (Vicia faba) and quinoa (Chenopodium quinoa Willd) showed significantly increased NPU. One NIS-portion supplied 10–20% of recommended fiber daily intake. Addition of quinoa flour had a positive effect on the FeDa% as did broad bean flour on ZnDa%. EDTA increased Fe- and ZnDa% in all NIS-products, but it also impaired sensorial quality (Jiménez, et al., 2016) [17].

Consumption of quinoa flakes results in significant reductions in serum triglyceride, total cholesterol and LDL-cholesterol and an increase in GSH – glutathione stimulating hormone, vitamin E concentrations and lower retention of total tocopherols and α-tocopherol in the extrudates (Carvalho et al., 2013) [7].

Roasted quinoa seeds flour at 177 °C for 15, 30 and 45 min resulted in increase in peak and final viscosity of cakes, weakening of starch–protein interactions and swelling of the starch granules, leading to granule rupture and decreased geometric mean diameters with elevated roasting temperatures (Rothschild et al., 2014) [37].

Baking: Baking red and yellow quinoa seeds resulted in increased total phenolic content and antioxidant activity. This increase in antioxidant activity might have been due to the Maillard reaction products produced during the thermal processing (Brend et al., 2012) [3].

High pressure – high temperature processed quinoa products resulted in increased iron solubility two to four times after soaking and germination, 3-5 times after fermentation, 5-8 times after fermentation of the germinated flour. 5-8 times in magnesium content has been improved after cooking and baking and copper content was reduced by 28% after processing (Ruiz, G.A et al., 2016) [30].

Table 2: Processing techniques

<table>
<thead>
<tr>
<th>Quinoa-derived product</th>
<th>Production method</th>
<th>Uses</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Treated seeds</td>
<td>Superheated steam treatment to expand the seeds and reduce cooking time. Mechanical abrasion, washing, or a combination to debitter seeds.</td>
<td>Favoring or texturizing agents in food products</td>
<td>Thomas, 1995 [48] Scanlin and Burnett, 2010 [41]</td>
</tr>
<tr>
<td>Beverages</td>
<td>Seeds are soaked, malted, kilned, mashed, cooled, and fermented with yeast. Mixing of quinoa extract, tiger nut (Cyperus esculentus), and α-amylases for hydrolysis of starches to thermostable maltodextrin within a beverage formulation.</td>
<td>Gluten-free fermented alcoholic beverage Substitute for animal or plant-derived milk</td>
<td>Kamelgard, 2013 [24] Felipe, 2003 [15]</td>
</tr>
<tr>
<td>Lipid</td>
<td>Extraction and molecular distillation to obtain a refined oil.</td>
<td>Dermatological use</td>
<td>Msika, 2012 [29]</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>Extraction of maltodextrin via alkali or enzyme treatment to produce a gel-form to deliver quinoa-derived peptides. Use of quinoa starches of specific shape and particle size.</td>
<td>Cream substitute that mimics the mouth feel of fat/cream in food</td>
<td>Singer et al., 1990 [46]</td>
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</table>

Near-infrared spectroscopy (NIRS) technology allowed the determination of protein (16.0–20.2 g 100g⁻¹), crude fiber (1.8–3.1 g 100g⁻¹), fat (4.4–7.5 g 100g⁻¹), calcium (298.8–1164.5 mg kg⁻¹), iron (0–948.5 mg kg⁻¹) and phosphorus (2735.0–4543.3 mg kg⁻¹). Provides an alternative for the determination of chemical compounds of quinoa, faster and at lower cost, with results comparable with chemical methods (Escuredo et al., 2014) [12].

Pinel et al. 2015 [34] developed quinoa milk with increased amount of protein and low glycemic index do not contain any prolamins that are toxic for people who suffer from celiac disease. This is a novel alternative to current milk-products
which has a beneficial effect for lactose intolerance population and is an excellent substitute for lactose intolerance.

Takao et al., 2005 [47] extracted the protein fraction (QP), The QP supplementation significantly prevented the increase in plasma and liver total cholesterol level, cholesterol biosynthesis was suppressed through the expression of mRNA of 8-hydroxy--methylglutaryl coenzyme A reductase in the liver, whereas the expression of cholesterol-1a-hydroxylase, a cholesterol catalytic enzyme, was found to be stimulated. This QP binds with bile acid, potentially reducing the micelle cholesterol solubility and inhibiting intestinal tract cholesterol absorption thereby hypocholesterolemic effect.

Heath benefits of quinoa products: It is stated that quinoa may benefit high-risk group consumers, such as children, the elderly, high-performance sports people, individuals with lactose intolerance, women prone to osteoporosis, people with anemia, diabetes, dyslipidemia, obesity, and celiac disease due to its properties including a high nutritional value, therapeutic features, and gluten-free content (Table 3). These features are considered to be linked with the existence of the fiber, minerals, vitamins, fat acids, antioxidants, and especially phytochemicals in quinoa, and they provide quinoa a big advantage over other crops in terms of human nutrition and health maintenance.

Table 3: Health benefits of quinoa products.

<table>
<thead>
<tr>
<th>Therapeutic application</th>
<th>Treatment</th>
<th>Endpoints (measured before and after intervention) and outcomes</th>
<th>Conclusions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child growth &amp; development</td>
<td>Infant food formulated from quinoa (100 g × 2/d for 15 days) compared with no treatment</td>
<td>↑ Plasma levels of IGF-1, a marker of malnutrition, known to increase body weight gain</td>
<td>Quinoa-based infant food may play a role in reducing childhood malnutrition</td>
<td>Ruales, 2002 [38]</td>
</tr>
<tr>
<td>Celiac disease</td>
<td>Cooked quinoa (50 g/d for 6 weeks)</td>
<td>All gastrointestinal parameters surface-enterocyte cell height, number of intra-epithelial lymphocytes per 100 enterocytes) Improved, serum lipid levels remained normal with small decrease in total cholesterol, LDL, HDL, and triglycerides</td>
<td>Quinoa is safe for consumption by celiac patients</td>
<td>Zevallos, 2014 [51]</td>
</tr>
<tr>
<td>Risk of cardiovascular disease</td>
<td>Quinoa cereal bar daily for 30 days</td>
<td>↓ Triglycerides ↓ Cholesterol ↓ LDL</td>
<td>Quinoa intake may reduce risk of developing cardiovascular disease</td>
<td>Farinazzi-Machado, 2012 [14]</td>
</tr>
<tr>
<td>Postmenopausal symptoms</td>
<td>Quinoa flakes (QF) compared with corn flakes (CF), 25 g/d for 4 weeks</td>
<td>QF consumption increased protein and fiber intake but not total caloric intake ↓ triglycerides, ↓ TBARS ↓ Cholesterol, ↓ LDL, ↑ GSH</td>
<td>Quinoa intake beneficially modulates metabolic parameters</td>
<td>De Carvalho, 2013 [7]</td>
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Conclusion
Pseudocereals are potential crops for food security across the world. Owing to their high nutrient content and quality of proteins. This has low glycemic effect on the blood glucose levels which has a protective effect against diabetes, cardiovascular disease. Quinoa essentially composed by globulins and albumins which contain less glutamic acid and proline than prolamins, and high essential amino acids content such as lysine, methionine, cystine, and histidine. Quinoa has the potential to shed its underutilized status and become an important industrial and food crop of the 21st century. Processing of quinoa resulted in easy digestion and absorption of protein, reduction of antinutritional contents like saponins, phytates, and tannins and increased bioavailability of minerals like magnesium, manganese, iron and zinc which has beneficial results in reduction and prevention of physiological and neurological disorders due to the application of processing techniques.

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