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Nutritional Value and Use of the Andean Crops Quinoa (*Chenopodium quinoa*) and Kañiwa (*Chenopodium pallidicaule*)

R. Repo-Carrasco,[1] C. Espinoza,[2] and S.-E. Jacobsen[3,*]

[1]Universidad Nacional Agraria La Molina, Facultad de Industria Alimentarías, Av. la Universidad s/n, Lima, Peru
[2]Universidad Nacional del Centro, Huancayo, Peru
[3]International Potato Center (CIP), Lima, Peru

ABSTRACT

Quinoa (*Chenopodium quinoa* Willd.) and kañiwa (*Chenopodium pallidicaule* Aellen) are native food plants of high nutritional value grown in the Andean region and used as food by the Incas and previous cultures. Quinoa and kañiwa served as a substitute for scarce animal proteins and are still one of the principal protein sources of the region. The importance of these proteins is based on their quality, with a balanced composition of essential amino acids similar to the composition of casein, the protein of milk. According to studies at the Universidad Nacional Agraria La Molina (UNALM), quinoa and kañiwa have a very high chemical score, and one cultivar of quinoa, Amarilla de Marangani, does not have any limiting amino acid.

It is also important to recognize and utilize the relatively high quantity of oil in quinoa and kañiwa. These grains can be a potential raw material for oil extraction. The highest percentage of fatty acids present in these oils is Omega 6 (linoleic acid), being 50.2% for quinoa and 42.6% for kañiwa. The fatty acid composition is similar to corn germ oil. The concentrations of γ- and α-tocoferol were for quinoa 797.2 and 721.4 ppm, and for kañiwa 788.4 and 726 ppm, respectively.

Quinoa and kañiwa can been utilized in weaning food mixtures. Two dietary mixtures have been formulated: quinoa-kañiwa-beans and quinoa-kiwicha-beans, with

*Correspondence: S.-E. Jacobsen, Royal Veterinary and Agricultural University, Department of Agricultural Sciences, Højbakkaard Alle 9, DK-2630, Taastrup; E-mail: seja@kvl.dk.

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high nutritional value. The mixtures had PER values close to that of casein: 2.36 and 2.59, respectively (casein 2.5). Also, elderly people and those with a need to lose weight can benefit from consumption of quinoa and kañiwa. The high content of dietary fiber has many positive health effects, for example, it can reduce the level of cholesterol in the blood and improve digestion. For this reason, consumers in developed countries may also have an interest in including quinoa into their diet.

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) and kañiwa (*Chenopodium pallidicaule* Aellen) are native food plants of the Andean region, dating back to 5000 years AD. The Incas appreciated their high nutritional value, and the ease in milling these crops made it possible for the rural populations to take advantage of their nutritional value. The consumption of quinoa and kañiwa has substituted for the lack of animal protein, and in many areas, quinoa and kañiwa are still principal protein sources (Tapia, 1997).

In Peru, there are serious nutritional problems, particularly among weaning and preschool children. The problem is most serious in the rural highlands, where nearly 50% of the population is below the poverty level. Inadequate nutrition practices are not only a result of economic problems but also of ignorance. The highly nutritive, native crops quinoa, kañiwa, kiwicha (*Amaranthus caudatus*), and tarwi (*Lupinus mutabilis*), are not staple crops in urban areas, and unfortunately, the current tendency is to replace them with cheap imported food products like rice and pasta. If this development is not changed, the production of native products will cease to be competitive, and they may completely lose their market. To face this problem, local raw materials should be included in food aid programs, specifically directed toward children of low-income families (Ayala, 1999; Rivera, 1999). To achieve this, efforts must be made to design appropriate small-scale low-cost food-processing technologies and develop new products, in order to encourage small companies to process Andean crops and produce nutritive foods (Jacobsen and Mujica, 2000; Mujica et al., 1999a,b).

One of the most serious problems affecting families in rural areas is their limited access to commodities, due to a lack of income. The occurrence of natural disasters such as droughts, also tends to create severe shortages of food for relatively long periods. As part of their survival strategy under such conditions, it is essential for peasants to rely on a number of easily accessible products that are adapted to the harsh weather conditions. For example, Andean grains and tubers [quinoa, kañiwa, kiwicha, tarwi, oca (*Oxalis tuberosa*), olluco (*Ullucus tuberosus*), etc.], which are resistant to adverse climatic conditions and are accessible to peasant families, can be used to improve their food supply as well as their income, if introduced to the market.

Rural agroindustries are dependent on low-cost, easy-to-manage technologies. UNALM is studying the use of low-cost extrusion technology to process Andean crops. For a very long time, Andean crops have been important ingredients in the diets. These native crops have a very high nutritional value and are well adjusted to Andean conditions. But, their importance has diminished with introduction of new species and products, often cheaper but of inferior quality. Consequently, it is important to develop new technologies and products that might increase their consumption and open larger markets.

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Homemade food products, or locally processed foods can increase the food supply for children in developing countries. The cooking/extrusion technology has already been tested successfully in Sri Lanka, Costa Rica, Tanzania, and Vietnam. The advantages of this technology are low cost, moderate production volumes, simple operation, minimum auxiliary equipment, versatility, good sanitary conditions, and easy management (Harper, 1981).

CHEMICAL COMPOSITION AND NUTRITIONAL VALUE OF QUINOA AND KAÑIWA

Protein

The nutritional quality of a product depends on the quantity and the quality of the nutrients. Quinoa and kañiwa do not have an exceptionally high protein content compared with other grains. The composition of some cereals and grains is shown in Table 1. The range of the chemical constituents for each grain varies according to cultivar.

The importance of the proteins of the Andean species is based on their quality. The proteins of quinoa and kañiwa mainly belong to albumin and globulin (Table 2), which have a balanced composition of essential amino acids similar to the composition of casein, the protein of milk. Brinegar and Goundan (1993) isolated and characterized the principal protein of quinoa, the chenopodina. The chenopodina, a globulin 11S type protein, separated by electrophoresis into two subgroups of chenopodina, A and B. These subgroups had molecular weights of 32,000–39,000 and 22,000–23,000, respectively, which are higher than for casein (Ranhotra et al., 1993). The amino acid compositions of quinoa and other grains are presented in Table 3. The leaves of quinoa also have a high

Table 1. Composition of cereals and Andean grains (g/100 g dry matter) (Kent 1983; Repo-Carrasco, 1992).

	Protein	Fat	Raw fiber	Ash	Carbohydrate
Wheat					
Manitoba	16.0	2.9	2.6	1.8	74.1
English wheat	10.5	2.6	2.5	1.8	78.6
Barley	11.8	1.8	5.3	3.1	78.1
Oats	11.6	5.2	10.4	2.9	69.8
Common rye	13.4	1.8	2.6	2.1	80.1
Triticale	15.0	1.7	2.6	2.0	78.7
Rice	9.1	2.2	10.2	7.2	71.2
Corn	11.1	4.9	2.1	1.7	80.2
Sorghum	12.4	3.6	2.7	1.7	79.7
Quinoa	14.4	6.0	4.0	2.9	72.6
Kañiwa	18.8	7.6	6.1	4.1	63.4
Kiwicha	14.5	6.4	5.0	2.6	71.5

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Table 2. Protein fractions of quinoa and kañiwa (percent of total protein) (Scarpati de Briceño, 1979).

	Albumins + globulins	Prolamins	Glutelins + insoluble proteins
Quinoa	45	23	32
Kañiwa	41	28	31

content of good-quality proteins, and they are additionally rich in vitamins and minerals, especially calcium, phosphorus, and iron.

Repo-Carrasco (1991) analyzed the amino acids of quinoa and kañiwa (Table 4). One variety, Amarilla de Marangani, did not have any limiting amino acid. All the cultivars of quinoa and kañiwa showed a high chemical score.

Lipids

There is a relatively high quantity of oil in quinoa and kañiwa, an aspect that has not been studied at any depth, making these grain crops potential sources for oil extraction. UNALM has studied the lipid fraction of quinoa and kañiwa, and determined the fatty acid and tocopherols composition. The raw materials utilized in this research were the quinoa

Table 3. Content of amino acids in grains (g amino acid/16 g of nitrogen) (Repo-Carrasco, 1992).

	Quinoa	Kañiwa	Kiwicha	Rice	Wheat
Aspartic acid	7.8	7.9	7.4	8.0	4.7
Treonine	3.4	3.3	3.3	3.2	2.9
Serine	3.9	3.9	5.0	4.5	4.6
Glutamic acid	13.2	13.6	15.6	16.9	31.3
Proline	3.4	3.2	3.4	4.0	10.4
Glycine	5.0	5.2	7.4	4.1	6.1
Alanine	4.1	4.1	3.6	5.2	3.5
Valine	4.2	4.2	3.8	5.1	4.6
Isoleucine	3.4	3.4	3.2	3.5	4.3
Leucine	6.1	6.1	5.4	7.5	6.7
Tyrosine	2.5	2.3	2.7	2.6	3.7
Phenylalanine	3.7	3.7	3.7	4.8	4.9
Lysine	5.6	5.3	6.0	3.2	2.8
Histidine	2.7	2.7	2.4	2.2	2.0
Arginine	8.1	8.3	8.2	6.3	4.8
Methionine	3.1	3.0	3.8	3.6	1.3
Cystine	1.7	1.6	2.3	2.5	2.2
Tryptophane	1.1	0.9	1.1	1.1	1.2
% N of the grain	2.05	2.51	2.15	1.52	2.24
% protein	12.8	15.7	13.4	9.5	14.0

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Table 4. Content of essential amino acids and chemical calculation of quinoa and kañiwa.

	Quinoa: A.de Marangani, a.a. g/16 N	Calculation[a]	Kañiwa: NG-06 a.a. g/16 g N	Calculation[a]
Isoleucine	3.9	1.00	3.2	1.00
Leucine	6.9	1.00	6.5	0.98
Lysine	6.3	1.00	5.7	0.98
Methionine + cystine	3.7	1.00	2.9	1.00
Phenylalanine + tyrosine	7.2	1.00	6.8	1.00
Threonine	3.4	1.00	3.1	0.91
Tryptophane	1.1	1.00	1.2	1.00
Valine	4.6	1.00	4.0	1.00
Chemical score		1.00		0.91
Limiting amino acid		—		Threonine

[a] FAO/WHO (1985).

cultivar Huancayo and white kañiwa. Oil extraction was carried out with hexane at 55°C utilizing four different milling treatments to determine yield. For quinoa, desaponification treatments were done before the milling. A complete statistical analysis of random block design was carried out in order to determine the optimal treatment to obtain the highest yield of oil extraction. Characterization of the lipid fraction was done in accordance with the methodology proposed by the AOAC (1990). The fatty acids were determined by gas chromatography, and the tocopherols were determined by high-performance liquid chromatography (Chaquibol, 1996).

The best treatment for the two grains was milling with sieve 30 (0.0232″), giving an oil yield for quinoa of 4.6% and for kañiwa of 6.4%. The oils of quinoa and kañiwa had specific gravity of 0.930121 and 0.935872, respectively. The indices of refraction were 1.4732 for quinoa and 1.4735 for kañiwa. The iodine value in measure of the degree of unsaturation of the oil, is high for the two oils: quinoa 127.81 and kañiwa 121.14. Thus, a high content of unsaturated fatty acids in these oils can be expected. The percentage of free fatty acids was 0.09 for quinoa and 0.14 for kañiwa. The index of saponification for quinoa was 195 and for kañiwa 187. The insaponifiable material found in quinoa was 5.01 and in the kañiwa 4.20.

Based on the fatty acids content, the highest percentage of fatty acids present in these oils was Omega 6 (linoleic acid), being 50.2% for quinoa and 42.6% for kañiwa. These values are similar to those found in corn germ oil, with a range from 45–65%. Omega 9 (oleic acid) is the second most common fatty acid, in quantities of 26.0 for oil of quinoa and 23.5% for oil of kañiwa. The content of Omega 3 (linolenic acid) was 4.8 for oil of quinoa and 6.0 for oil of kañiwa, and the content of palmitic acid for oil of quinoa was 9.59 and for kañiwa 17.94. Fatty acids, such as stearic and eicosapentanoic acid, were found in small quantities.

As indicated by the high iodine value, 82.7% of the fatty acids in quinoa oil and 72.9% of kañiwa oil are unsaturated. In the last decades, unsaturated fatty acids have gained

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importance because of various beneficial functions. For example, they play a very important role in maintaining the fluidity of cell membranes.

Concentration of tocopherols in quinoa were 797.2 ppm of γ-tocopherol and 721.4 ppm of α-tocopherol, and for kañiwa 788.4 ppm and 726 ppm of γ- and α-tocopherol, respectively. The tocopherols exist as four different isomers with antioxidant power, that is in decreasing order: $\delta > \gamma > \beta > \alpha$. The concentration of γ-tocopherol in the obtained oils is slightly higher than in corn germ oil, which has 251 ppm of α-tocopherol and 558 ppm of γ-tocopherol. The high content of oil in quinoa and kañiwa guarantee a long shelf life, due to the antioxidant power of the γ-tocopherol.

In addition, the content of α-tocopherol, as vitamin E, in quinoa is important. This vitamin acts as an antioxidant at the cell membrane level, protecting the fatty acids of the membranes against damage caused by free radicals.

Wood et al. (1993) found that 11% of the total fatty acids of quinoa were saturated, with palmitic acid predominant. The linoleic, oleic, and alpha-linolenic acids were the predominant unsaturated acids with concentrations of 52.3, 23.0, and 8.1% of the total fatty acids, respectively. They also found erucic acid at approximately 2%. Przybylski et al. (1994) found linoleic acid as the principal fatty acid (56%) in quinoa, followed by oleic acid (21.1%), palmitic acid (9.6%), and linoleic acid (6.7%). According to these authors, 11.5% of the total fatty acids of quinoa are saturated.

Carbohydrates and Fiber

Starch is the most important carbohydrate in all grains, making up approximately 60–70% of the dry matter. In quinoa, the starch content is 58.1–64.2% (deBruin, 1964). In the plants, the starch is present in granular form. The granules of different species have a characteristic size and shape. The granules of quinoa starch have a diameter of 2 μm, being smaller than starch of the common grains. The starch of quinoa has been studied very little, and that of kañiwa even less. Ahamed et al. (1998) mentioned that the quinoa starch has an excellent stability under freezing and retrogradation. These starches might be an interesting alternative to replace chemically modified starches. The gelatinization temperature for different quinoa cultivars was in the range of 55.5–72.0°C, and the amylose content was 14.3–27.7% (Bacigalupo and Tapia, 1997). Thus, it will be useful to study their functional properties.

Ahamed et al. (1998) found 3–4% pentosans, and the content of starch in red, yellow, and white cultivars was 59, 58, and 64%, respectively. Furthermore, in addition to polysaccharides, the grains of quinoa and kañiwa also have free sugars in small quantities. The Andean crops have higher sugar content than common grains (Table 5).

Minerals

In Table 6, the mineral content in quinoa and other grains is shown. Quinoa has a high content of calcium, magnesium, iron, copper, and zinc.

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Table 5. Sugar content in Andean grains (g/100 g dry matter) (Repo-Carrasco, 1992).

	Glucose	Fructose	Sacarose	Maltose
Quinoa	1.70	0.20	2.90	1.40
Kañiwa	1.80	0.40	2.60	1.70
Kiwicha	0.75	0.20	1.30	1.30

Saponins

The saponins are present in many plant species, including spinach, asparagus, alfalfa, and soybeans. The content of saponins varies in quinoa between 0.1 and 5%. The pericarp of the quinoa grain contains saponins, giving it a bitter flavor. It is necessary to eliminate the saponins before the grain can be consumed. The saponins, in addition to the bitter taste, cause foam formation in water solutions. The saponins in quinoa form a stable foam in very low concentrations, 0.1%.

Chemically, the saponins are glucosides that, upon hydrolysis, liberate one or more sugar units and free aglycon sugar, or sapogenins. Sapogenins can have a steroid or triterpenoid structure. The quinoa saponins are triterpenoid, and the principal sapogenin is oleanolic acid (Burnouf-Radosevich and Delfl, 1984). In a recent study, Jacobsen et al. (2000) described several saponins, some of which were not isolated previously in quinoa. Four sapogenins, oleanolic, phytolaccagenic, spergulagenic acids, and hederagenin, were isolated.

Saponins lower surface tension, have an emulsifying function, and have a hemolyzing effect on red blood cells. They are toxic to cold-blooded animals. The hemolytic and antilipemic activity, and its capacity to lower the cholesterol level in blood serum, might be considered its most important positive characteristics. No negative effects of the saponins have been found on the digestibility of proteins.

Table 6. Mineral constituents of cereals and Andean grains (mg/100 g of dry matter) (Kent, 1983).

	Wheat	Barley	Oats	Rye	Triticale	Rice	Quinoa	Kañiwa	Kiwicha
Ca	48	52	94	49	37	15	94[a]	110[a]	236[a]
Mg	152	145	138	138	147	118	270[b]	n.r.	244[c]
Na	4	49	28	10	9	30	11.5[b]	n.r.	31[c]
P	387	356	385	428	487	260	140[a]	375[a]	453[a]
Fe	4.6	4.6	6.2	4.4	6.5	2.8	16.8[a]	15.0[a]	7.5[a]
Cu	0.6	0.7	0.5	0.7	0.8	0.4	3.7[b]	n.r.	1.21[c]
Zn	3.3	3.1	3.0	2.0	3.3	1.8	4.8[b]	n.r.	3.7[c]

n.r. = not reported.
[a] Collazos (1993).
[b] Latinreco (1990).
[c] Becker et al. (1981).

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Quinoa can be classified in accordance with the saponin concentration as either sweet (free from or containing less than 0.11% of free saponins on the basis of fresh weight) or bitter (containing more than 0.11% of saponins) (Koziol, 1993).

PROCESSING AND USES

The methods of elimination of saponins in quinoa can be classified as moist and dry methods (Mujica and Jacobsen, 1999). The moist methods are the methods traditionally utilized by farmers. The grains are washed while being rubbed with the hands or by a stone. Bacigalupo and Tapia, (1997) describe a traditional method in Bolivia, where a stone with a diameter of 50 cm is used, and underneath is placed quinoa seeds mixed with coarse sand. The mixture is exposed to sun for a couple of hours until it is heated, causing expansion of the pericarp, which thereafter is easily removed. At the industrial level, equipment for quinoa washing is available. The moist method is efficient for saponin elimination; however, the problems are the high cost of drying the product and disposing of wastewater containing saponins. Another risk is that the grains may begin to germinate during the washing and drying process, because quinoa has a very high germinative power. At the UNALM, an experimental washing equipment was designed (Molina, 1972). The most favorable washing conditions were a soak period of 30 min, a stirring period of 20 min, and a water temperature of 70°C.

The dry methods (scarification or abrasive dehulling) utilize machinery to polish the grains in order to eliminate saponins. This method is cheaper than washing but has the disadvantage that it does not eliminate all the saponin. If the efficiency is increased, and the grain is burnished more intensely, some nutrients are lost, as the proteins are mainly present in the exterior layer of the grain. The most recommended method for saponin elimination is the combination method, where the quinoa is first quickly burnished, and afterwards, it is briefly washed. With the brief washing, the costs of drying are lower, and the previous burnishing lowers the concentration of saponin in the wastewater.

Once the saponins have been eliminated, the quinoa can be consumed as entire grains or be processed in different ways. Quinoa can be milled to flour for preparation of bread and pastry, or in mixtures of flours for infant food. Repo-Carrasco (1992) obtained yields of flour of prewashed quinoa of 60% and of precooked quinoa of 63.7%. Quinoa flour can partially replace wheat flour, in bread up to 20% and in pastry up to 50%.

Few studies on extrusion of quinoa have been conducted. One of the oldest is Romero et al. (1985), who studied the effect of extrusion on the functional and nutritional characteristics of quinoa. Also, the use of quinoa for extrusion has been studied in mixtures with corn (Coulter and Lorenz, 1991a,b). The quinoa was utilized at three levels (10, 20, and 30%), and the chemical composition, nutritional profile, and organoleptic characteristics of the products were analyzed. High protein values were found in the endproducts, with good consumer acceptance. The UNALM is currently conducting studies on low-cost extrusion in quinoa processing, working with the variety Kancolla at different levels of initial moisture (14, 15, 16, 17, and 18%). A moisture of 15% seems to be ideal with regard to expansion of the product, a result that coincides with the results of Coulter and Lorenz (1991a)). Preliminary tests of extrusion of kañiwa and kiwicha have also been conducted.

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Main product kañiwa is mainly consumed as kañiwako, which is toasted and milled grains. The grain is toasted carefully to avoid burning, it is then ventilated in order to eliminate the released perigoniums, and finally, it is milled. The result is an aromatic product that is consumed with sugar, milk, and water. Flour of kañiwa can be utilized in bread, noodles, and pastry. Some varieties of kañiwa expand when toasted and can be included in sweets and snacks.

Quinoa and kañiwa can be utilized in weaning food mixtures. In a study conducted by Repo-Carrasco and Li Hoyos (1993), two dietary mixtures with high nutritional value were formulated: quinoa-kañiwa-beans and quinoa-kiwicha-beans. The mixtures had PER values close to that of casein: 2.36 and 2.59, respectively (casein 2.5). Also, elderly people and those with a need to lose weight can benefit from consumption of quinoa and kañiwa. The content of dietary fiber has various positive health effects, such as reducing the level of the cholesterol in the blood and improving digestion. For this reason, consumers in developed countries may be interested in including quinoa in their diets.

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