A lesser-known grain, *Chenopodium quinoa*: Review of the chemical composition of its edible parts

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Abstract

In this era of ever-increasing world population, newer food and feed crops that have been hitherto neglected are gaining recognition. The rejection of such lesser-known food crops has been due not to any inferiority but to the lack of research resources in the place of origin and often to their being scorned as "poor people's plants." The genus Chenopodium *supplies tasty and nutritious leaves as well as pink- to cream-coloured edible seeds. Tolerance to cold, drought, and salinity and the high lysine content of the seed protein are the attractive features of quinoa* (Chenopodium quinoa)*, the most frequently consumed species in the Andean regions of South America, Africa, some parts of Asia, and Europe. This review compares and evaluates the nutritional and antinutritional constituents of the leaves and seeds of* C. quinoa *vis-à-vis their conventional counterparts and argues for the acceptance of this plant in human diets.*

Introduction

Most of the world's food today comes from a mere 20 or so plant species. Throughout history mankind has used some 3,000 plant species for food, but over the centuries the tendency has been to concentrate on fewer and fewer. The rejection of lesser-known food crops has not been due to any inherent inferiority. Many have been overlooked merely because they are native to the tropics, a region generally neglected because the world's research resources are concentrated in the temperate zones. Others are neglected because they are scorned as "poor people's plants."

Quinoa (*Chenopodium quinoa)* is one of the lesser-known food crops, a poor people's crop that is native to the Andean regions of South America [1]. In contrast to maize, potatoes, and *Phaseolus* beans, all of which are staple crops originating from the Andes, quinoa has not attained global importance, possibly because the bitter, antinutritional saponins [2] need to be removed from the seed before cooking or processing [3].

Quinoa has an exceptionally attractive amino acid balance for human nutrition because of its high level of lysine. The tasty and nutritious leaves and seeds are consumed frequently in the Andean regions of South America, Africa, some parts of Asia, and Europe. The plant is native to Peru, and the seeds are used whole in soups or ground into flour to make bread and cakes [4]. The seeds are also used as poultry feed, in medicine, and for making beer.

Agronomic aspects of *Chenopodium*

C. quinoa is a dicotyledonous plant and is botanically classified as follows [5]:

Subclass:	Dicotyledoneae
Group:	Thalamiflorae
Order:	Caryophyllales
Family:	Chenopodiaceae
Genus:	*Chenopodium*
Species:	*quinoa*

The family Chenopodiaceae is composed of herbs and shrubs, or rarely small trees, that usually grow in alkaline soil. The plants are usually scruffy because of their external cells that dry into white flakes. The leaves are simple, sometimes more or less succulent or reduced to small scales, and usually alternate but rarely opposite. There are no stipules and the flowers are bisexual or rarely unisexual [6].

The family is found worldwide but it is centred in alkaline areas. Some species are restricted to wet, salty, or alkaline soil, such as that of coastal marshes or alkaline plains and desert areas. On the whole, the family is made up of weedy plants. Some of the more important genera are *Chenopodium* (goosefoot, pigweed, or lamb's quarters), *Kochia* (red sage), and *Salsola* [5].

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The genus *Chenopodium* has a worldwide distribution and contains about 250 species [3]. About eight species are found in India [7]. Some species of *Chenopodium* and the countries in which they are found are listed in table 1 [8]. *Chenopodium* species have been considered weeds [9], and many efforts have been directed towards their eradication [10].

Interest in quinoa as a valuable food source has been renewed in Asia in recent years because of its versatility and its ability to grow under conditions normally inhospitable to other grains. These include low rainfall, high altitude, thin cold air, hot sun, and sub-freezing temperatures.

The average yield of the fruit, as reported by Simmonds [11], is 840 to 3,000 kg/ha, whereas Weber [12] reported yields for quinoa as low as 450 kg/ha to a record of 5,000 kg/ha, with an average yield of 800 to 1,000 kg/ha. Quinoa is extensively grown in Peru and Bolivia. Because of its resistance to frost and drought, it is very suitable for cultivation in highlands and temperate regions. Production of quinoa in Ecuador has gone from backyard cultivation to extensive cultivation. In 1987 around 431 ha were harvested, producing 720 tonnes.

Quinoa as a vegetable

Quinoa leaves are widely used as food for humans and livestock [12] and constitute an inexpensive source of vitamins and minerals. Generally, the younger leaves are used for human food. The correlation between the nutrient content of a leaf and its age (as shown by its position on the plant) is an important factor in choosing leaves for harvesting. *Chenopodium* leaves have more protein and minerals than commonly consumed spinach and cabbage but less than amaranth leaves. The leaves of *Chenopodium* species contain from 3% to 5% dry weight nitrate [8]. The nitrate content in amaranth leaves ranges from 0.8% to 2% [13]. However, most of the nitrate is concentrated in the stem portion, which is generally discarded [8]. The oxalate content of *Chenopodium* leaves ranges from 0.9 to 3.9 g/100 g fresh weight, concentrated mainly in the stems [8]. Flavonoids have been identified in five species of *Chenopodium*. Quercitin (a flavonol) was found in all five species, kaempferol in four, and isorhamnelins in one [14]. The biological function of these flavonoids could be to provide resistance against viruses [15].

The amino acid composition of quinoa leaves as compared with that of other leafy vegetables is given in table 2. The higher content of lysine and lower content of methionine are its most distinguishing features.

Quinoa leaves can also be eaten in salads and are important in regions where vegetables are scarce. The leaves and stems are also fed to ruminants, and the chaff and the gleanings are generally fed to pigs.

TABLE 1. Distribution of some *Chenopodium* species[a]

Species	Countries
C. *quinoa,* C. *pallidicaule*	Argentina, Bolivia, Chile, Guatemala, Peru
C. *berlandieri*	Mexico
C. *album*	India (valleys of Himalayas)
C. *ambrosoides*	India
C. *amaranticolor*	India
C. *murale*	India
C. *striatum*	Czechoslovakia
C. *opulifolium*	Czechoslovakia
C. *foliosum-polyspermum*	Finland

Source: ref. 8.
a. Hybrids available: *C. album-quinoa, C. foliosum-polyspermum.*

Quinoa seed

C. quinoa is a starchy, dicotyledonous seed, not a cereal [17]. The small, round, flat seeds measure about 1.5 mm in diameter, and 350 seeds weigh about 1 g [18, 19]. Quinoa has been an important grain crop in the Andes for many centuries and now is gaining popularity elsewhere in the world. In comparison with the common cereals, quinoa generally has a higher content of lysine-rich protein (12%–19%; average, 15%), fat (5%–10%), and crude fibre (2%–3%). This makes it nutritionally superior to most cereal grains. Table 3 gives the proximate composition of quinoa in comparison with some other food grains. After mechanical abrasion, the α-amylase and protease activities of quinoa seeds increase [25]. High α-amylase activity is probably the cause of the low amylograph values of quinoa. The iron, calcium, and phosphorus levels are higher than those of maize and barley [13, 26].

The main food uses for quinoa are for soups, sweets, and a coarse bread called *kispina*. Various hot or fermented drinks can be prepared from it. High-protein cakes, cookies, and biscuits can be made by mixing up to 60% quinoa flour with wheat flour [12, 21]. The fermented beverage made from quinoa seeds is called *chicha*. Noodles can be made using 40% quinoa flour without affecting the appearance or other characteristics of the product. A number of recipes for cookies, chowders, croquettes, and casseroles using quinoa are available [27]. Quinoa can be germinated at 22°C in fresh water; the germination rate is 74% to 86%. However, germination at 0°C caused a decrease in the germination rate of 12% to 30% [28].

The protein, fat, and fatty acid composition of *Chenopodium* seeds is similar to that of amaranth [29].

TABLE 2. Amino acid composition of quinoa leaves compared with that of other leafy vegetables

Vegetable	Total N (g/100 g)	Amino acid (%)											
		Arg	His	Lys	Trp	Phe	Tyr	Met	Cys	Thr	Leu	Ile	Val
Quinoa	0.6	0.92	0.32	0.75	0.02	0.11	0.37	0.05	–[a]	0.17	0.41	0.41	0.29
Amaranth	0.6	0.24	0.13	0.25	0.07	0.18	0.19	0.07	0.04	0.14	0.37	0.29	0.28
Cabbage	0.3	0.45	0.13	0.24	0.07	0.20	0.12	0.06	0.07	0.22	0.34	0.23	0.26
Drumstick leaves	1.1	0.38	0.14	0.32	0.10	0.29	–[a]	0.11	0.13	0.25	0.46	0.28	0.35
Spinach	0.3	0.35	0.14	0.40	0.10	0.33	0.31	0.11	0.08	0.29	0.53	0.3	0.35

Source: ref. 16.
a. – trace or absent.

TABLE 3. Proximate composition (%) of quinoa seeds compared with that of other seeds

Seed	Moisture	Ash	Protein	Fat	Carbohydrate	Crude fibre
Quinoa	10–13	3	12–19	5–10	61–74	2–3
Amaranthus paniculatas	6–9	3–4	13–18	6–8	63	4–14
Wheat	13	2	14	2	69	1
Oats	8	2	14	8	68	1
Rice	15	1	8	1	78	2
Maize	15	2	13	4	66	3
Sorghum	12	2	12	2	73	2
Soya bean	8	5	47	21	14	4
Barley	13	2–3	12	1	70	4

Source: refs. 13, 16, 17, 19–24.

Protein content

Quinoa seeds contain high-quality protein [30] and large amounts of carbohydrates, fat, vitamins, and minerals. The seeds have a higher nutritive value than most cereal grains. The protein content of about 15% in quinoa is much higher than that found in cereals such as wheat, barley, oats, rice, and sorghum. The soluble protein contents in quinoa are similar to those in barley and higher than those in wheat and maize [26].

Table 4 gives the contents of essential amino acids in quinoa as compared with other grains. Quinoa protein contains large amounts of lysine, which is limiting in many plant proteins. The Sajma variety (developed in Bolivia) contains approximately twice as much lysine as whole wheat on a dry weight basis. The high levels of lysine in quinoa protein make it nutritionally superior to wheat. Dini et al. [31] reported lysine, with a chemical score of 83, as the limiting amino acid, although the level is higher than that for wheat and rice, with chemical scores of 31 and 40, respectively.

It is an interesting observation that methionine and cysteine (chemical score 127) and phenylalanine and tyrosine (chemical score 125) are limiting in other grains.

TABLE 4. Essential amino acid composition of quinoa seeds compared with that of other seeds

Seed	Amino acid (g/100 g protein)								
	Trp	Met	Thr	Ile	Val	Lys	Phe/Tyr	Leu	Cys
Quinoa	0.8–1.1	0.3–2.6	3.6–4.4	3.8–4.2	4.7–4.8	5.4–6.3	6.2–8.9	–[a]	0.6–1.4
Amaranthus cruentus (raw)	–[a]	4.1	3.4	3.6	4.2	5.1	6.0	5.1	2.1
A. cruentus (popped)	–[a]	3.7	3.5	3.6	4.3	4.3	6.0	5.2	1.8
A. edulis	1.1	4.0	3.8	3.9	4.5	5.7	7.8	5.9	2.3
Wheat	0.9	4.3	3.1	3.5	4.7	3.1	8.0	7.0	2.2
Oats	1.3	4.7	3.5	4.0	5.5	4.0	8.9	7.8	1.4
Soya bean	0.7	3.0	4.5	4.0	4.4	6.4	8.4	7.8	1.6
Corn	0.6	3.2	4.0	4.6	5.1	1.9	10.6	13.0	1.6
Rice	1.0	3.0	3.7	4.5	6.7	3.8	9.1	8.2	1.6
FAO/WHO standard	1.0	3.5	4.0	4.0	5.0	5.5	6.0	7.0	3.5

Source: refs. 13, 16, 17, 19, 20.
a. – trace or absent.

The ratio of tyrosine and phenylalanine to methionine and lysine is higher than FAO/WHO standards. Ruales and Nair [19] reported the aromatic amino acids tyrosine and phenylalanine, with a chemical score of 86, as the first limiting amino acids. However, the absence of gluten-like properties makes quinoa unsuitable for direct use in making bread. Telleria et al. [32] reported no differences in the amino acid composition of raw quinoa and quinoa seeds treated with water at different temperatures to remove saponins. Biological studies showed a decrease in protein efficiency ratio (PER) values after extraction at 85°C but not at 70°C.

White et al. [33] reported that the quality of quinoa protein was equal to that of dried milk protein when fed to rats. Pigs fed cooked quinoa were reported to grow as well as those fed dried skim milk [34]. Removal of saponins from the outer layers of the seeds increased the *in vitro* digestibility of the protein by 7% [35].

The protein content of seeds from Mexican *Amaranthus* spp. as well as South American *Chenopodium* spp. is 13% to 15%. Digestibility (53%–65%) improved when the seeds were toasted or popped (68%–78%). Their biological value was 73% and their PER [36] was similar to that of casein [1, 20]. Processes such as extrusion are known to improve the PER of quinoa flour [37].

In animal experiments, the net protein utilization (NPU) values of 76% and the biological value of 92 for protein in quinoa were comparable with those of other high-quality food proteins [38].

Lipid content

Quinoa seeds have approximately 9% fat on a dry weight basis. Quinoa fat has a high content of oleic acid (24%) and linoleic acid (52%) [38]. Quinoa oil is colourless to yellowish with a pungent, disagreeable, camphoraceous odour, characteristic of the seed. The flavour is bitter and burning.

Quinoa oil has been in use since the American Civil War. The original methods of production were quite primitive. The plants were boiled in iron pots equipped with soapstone lids. The oil condensed against the lids and was skimmed off. It was sold mainly in Baltimore, where the old name "Baltimore oil" is still used [39]. Maryland remains the chief producer of quinoa oil; the area of production is concentrated largely within a 25-mile radius in Carroll, Frederick, Howard, and Montgomery counties, with wood pine as the fuel for distillation. The total production in normal years varies between 60,000 and 80,000 lb. The yield depends on the weather conditions, the stage of maturity of the plant, and other factors. One acre of quinoa produces, on average, about 50 to 60 lb of oil per year.

On extraction with petroleum ether, quinoa yields yellow oil ranging from 6% to 8% of the weight of the whole seed, depending on the variety. The hulls, bran, and flour account for 10%, 40%, and 50%, respectively, of seed weight. The total fat contents in whole seed, hulls, bran, and flour extracted with diethyl ether were 7.6%, 5.7%, 11.6%, and 3.2%, respectively. The crude lipid content of quinoa was similar to that found in *Amaranthus caudatus*, a closely related plant [40, 41].

The constants of quinoa oil are compared with those of some selected edible oils in table 5. Quinoa seed oil is more unsaturated and also has a higher content of unsaponifiable matter than cereal oils.

Table 6 compares the fatty acid composition of quinoa seed oil and some other edible oils. Linoleic acid ($C_{18:2}$) accounted for over 50% of the fatty acids in quinoa oil, followed by oleic acid ($C_{18:1}$) and palmitic acid (C_{16}). The relatively high content of linolenic acid ($C_{18:3}$) in quinoa oil indicates an excellent nutritional quality of the grain. According to Morrison [44], the fatty acid composition of quinoa lipids is similar to that of wheat.

The ratio of polyunsaturated to saturated fatty acids (PS ratio) of quinoa oil is 4.9. This is higher than the PS ratios of most edible oils, such as soya bean oil (3.92), corn oil (4.65), and olive oil (0.65). The percentage of energy delivered by linoleic acid in quinoa seed oil is 10%, which is higher than the recommendation of the American Academy of Pediatrics that infant foods should contain at least 2.7% of their energy in the form of linoleic acid [38].

The percentage of free fatty acids is higher in quinoa

TABLE 5. Oil constants of quinoa seed oil compared with those of other seed oils

Variable	Oil				
	Quinoa	*A. paniculatas*	Wheat	Corn	Rice
% oil in whole seed	6–8	8	2	3–7	
% oil in bran	11–12	18–20	5–6		8–16
Specific gravity at 25°C	0.8910	0.9155	0.9248	0.9270	0.9192
Refractive index at 25°C	1.4637	1.47		1.3–2.0	
Saponification value	190	217	180–189	188–193	188
Iodine value	129	99.97	115–126	116–130	99.5
% unsaponifiable matter	5	5–8	4–9	1–2	4

Source: refs. 22, 23, 42.

TABLE 6. Fatty acid composition (%) of quinoa seed oil compared with that of other seed oils

Oil	Fatty acid										
	C_6	C_8	C_{10}	C_{12}	C_{14}	C_{16}	C_{18}	C_{20}	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$
Quinoa	–[a]	–	–	–	0.1	9.9	0.6	0.4	24.5	52.3	3.8
Amaranthus cruentus	–	–	–	–	–	13.4	2.7	0.7	20.4	62.1	1.1
Wheat	–	–	–	–	–	12.2	0.84	–	26.6	39.1	9.6
Corn	–	–	–	–	–	7.3	3.3	0.4	43.4	39.1	0.8
Rice	–	–	–	–	0.6	16.5	1.7	0.6	43.7	26.5	–
Coconut	0.5	9.0	6.8	46.4	18	9.0	1.0	–	7.6	1.6	–
Peanut	–	–	–	–	–	8.3	3.1	2.4	56	26	–
Soya bean	–	0.2	–	–	0.1	9.8	2.4	0.9	28.9	50.7	6.5

Source: refs. 13, 38, 43.
a. –Trace or absent.

seeds (18.9%) than in wheat (11%) and germinated barley (8.4%) [45]. Neutral lipids are predominant in cereals and have been reported to constitute around 90% of the lipids in members of the Amaranthaceae family [46] (table 7).

Quinoa oil contains squalene, an industrially useful unsaturated hydrocarbon, as the main constituent of unsaponifiable matter. Squalene is used as a bactericide and as an intermediate in many pharmaceuticals, organic colouring materials, rubber chemicals, and surface-active agents. Seven sterols have been identified in quinoa lipids, the major one being Δ^7-stigmasterol (43% of total sterols). The other sterols are cholesterol (3.6%), Δ^5-campesterol (2.3%), $\Delta^{5,22}$-stigmasterol (5.5%), Δ^7-campesterol (8%), $\Delta^{5,24\,(28)}$-avenasterol (21.7 %), and β-sitosterol (15%) [31].

Carbohydrate content

The chemical composition of some *C. quinoa* varieties harvested in the gardens of the tropical plant laboratory at Wageningen Agricultural University showed fairly small differences, except in starch content. Table 8 shows the carbohydrate profile of these varieties.

Quinoa starch has a granular diameter of 1 to 1.25 μ, a gelatinization temperature range of 57° to 64°C, an amylose content of 11% [47], and an average amylopectin chain length of 27 [48]. Processes such as extrusion and drum drying alter the starch digestibility, the values being 64% and 72% for the raw starch from

TABLE 7. Composition of lipids (% ± SD) in quinoa seeds

Component	Whole seed	Hulls	Bran	Flour
Lipids				
Neutral lipids	56 ± 0.6	40 ± 0.6	76 ± 0.7	70 ± 0.5
Polar lipids	25 ± 0.3	44 ± 0.5	13 ± 0.1	21 ± 0.2
Free fatty acids	19 ± 0.2	15 ± 0.1	11 ± 0.1	9 ± 0.1
Composition of neutral lipids				
Triglycerides	74 ± 0.6	72 ± 0.5	82 ± 0.1	8 ± 0.5
1,2-Diglycerides	13 ± 0.2	11 ± 0.2	8 ± 0.1	6 ± 0.1
Monoglycerides	3 ± 0.1	5 ± 0.1	2 ± 0.1	2 ± 0.1
Waxes	3 ± 0.1	2 ± 0.1	3 ± 0.1	1 ± 0.1
Composition of polar lipids				
Phosphatic acid	1 ± 0.1	1 ± 0.3	1 ± 0.02	0.4 ± 0.2
Phosphatyl serine	4.0 ± 0.1	3 ± 0.4	4 ± 0.04	3 ± 0.04
Phosphatidyl ethanolamine	19 ± 0.2	10 ± 0.1	13 ± 0.1	8 ± 0.04
Phosphatidyl inositol	11 ± 0.1	10 ± 0.1	6 ± 0.04	13 ± 0.1
Lysophosphatidyl ethanolamine	43 ± 0.2	43 ± 0.2	22 ± 0.2	7 ± 0.1
Phosphatidyl choline	12 ± 0.1	16 ± 0.1	48 ± 0.1	49 ± 0.1
Lysophosphatidyl choline	4 ± 0.1	3 ± 0.1	4 ± 0.1	3 ± 0.1
Monogalactosyl diglyceride	2 ± 0.0	1 ± 0.01	0.4 ± 0.01	3 ± 0.04
Digalactosyl diglyceride	3 ± 0.0	2 ± 0.02	1 ± 0.02	4 ± 0.05
Others	3 ± 0.1	3 ± 0.1	0.4 ± 0.02	0.2 ± 0.01

Source: ref. 22.

TABLE 8. Carbohydrate profile (%) of quinoa seeds

Carbohydrate	*C. quinoa* red	*C. quinoa* yellow	*C. quinoa* white
Starch (polarimetrically)	59	58	64
Starch (pancreatic method)	58	58	65
Reducing sugars	2	2–3	2
Crude fibre	2	3	2
Pentosans	3	3	4
Dietary fibre	ND[a]	9[b]	ND

Source: refs. 20, 23.
a. Not determined.
b. 8% insoluble dietary fibre and 2% soluble dietary fibre.

quinoa seeds [35]. The extremely small size of the starch granule can be beneficially exploited by using it as a biodegradable filler in polymer packaging [49]. Quinoa starch pastes do not gel on standing [50]. Its excellent freeze-thaw stability makes it an ideal thickener in frozen foods and other applications where resistance to retrogradation is desired [51].

Mineral and vitamin content

The mineral composition of some quinoa grains as compared with other grains is given in table 9. Quinoa seeds have a high concentration of potassium and phosphorus. The ratio of calcium to magnesium is 1:3 and that of calcium to phosphorus is 1:6, which is far greater than the recommended Ca:P ratio of 1:1.5 [52]. Although quinoa is not a cereal, it is often consumed instead of cereals. It contains more riboflavin and folic acid than common cereals such as wheat, barley, rice, and maize [53]. No trace of ascorbic acid has been found. This is probably due to oxidation of the vitamin C in the seeds during storage.

Quinoa satisfies the requirements for most vitamins recommended by the Committee on Dietary Allowances [52]. The process of removing saponins seems to alter the vitamin composition of quinoa to a minor degree [38]. Table 10 shows the vitamin composition of quinoa as compared with some other grains.

Antinutritional contents

The important antinutritional factors in quinoa seeds are saponins, protease inhibitors, and phytic acid. Reichert et al. [54] identified the bitterness of saponin as the limiting factor in the use of quinoa, but Chauhan et al. [17] showed that 34% of the total saponins are located in the hulls of quinoa seeds and can be removed by dehulling. The total amount of saponin remaining in quinoa seeds was much lower than that found in soya beans and some pulses [55].

Saponins

Saponins are widely distributed throughout the plant kingdom and have been identified in at least 400 species belonging to 60 different families. Common plants that contain saponins include spinach, beets, asparagus, alfalfa, and soya beans [56]. Saponins have been found in bulbs, roots, stems, fruits, leaves, and in some cases throughout the whole plant. The percentage of saponins varies in different plants, usually from 0.1% to 5% [57]. Saponins are uncommon in animals [58].

Several plant extracts used as flavouring agents in food contain active saponins. The majority of saponins are powerful haemolytics *in vitro*, but large doses are required to produce haemolysis on intravenous injection [42].

Saponins have a direct influence on the central nervous system, presumably affecting the permeability of the nerve cells. Initial symptoms of acute poisoning are violent convulsions and paralysis, followed by death. Small doses cause intestinal disorders and death after several days [56].

Most saponins are nitrogen-free glycosides, each consisting of a sapogenin and a sugar. The sapogenin may

TABLE 9. Mineral profile (mg/100 g) of quinoa seeds compared with that of other seeds

Mineral	Seed					
	Quinoa[a]	Wheat	Barley	Maize	Rice	Amaranth
Potassium	845–1,201	370	560	286	70–150	290–580
Calcium	70–874	29–48	10–80	30–90	0–40	25–389
Phosphorus	355–5,350	355	215–420	270–348	160–230	655
Magnesium	161–2,620	128	120	120–144	48–60	232–363
Sodium	2.7–22	3	3	1–16	8–9	7–100
Iron	6.3–81	11.5	3–10	2	3	18
Manganese	1.9–33	5	1.6	0.5	2	2–3
Zinc	1.2–36	2	1.5	2	2	4
Copper	0.7–10	0.5	0.8	0.19–0.21	0.3–0.7	1

Source: refs. 1, 13, 16, 17, 20, 23, 24, 28.
a. Values are given as ranges for different varieties and as reported by different investigators.

TABLE 10. Vitamin contents of raw quinoa seeds compared with those of other seeds

Vitamin	Seed					
	Quinoa[a]	Wheat	Barley	Maize	Rice	Amaranth
Vitamin A (mg/100 g)	0.02	–[a]	–	–	–	0
Vitamin C (mg/100 g)	16.4	0	0	0	0	3.36–7.24
Thiamine (mg/100 g)	0.2–0.4	0.45–0.49	0.47	0.42	0.06	0.17
Riboflavin (mg/100 g)	0.2–0.3	0.17	0.2	0.1	0.06	0.2
Folic acid (µg/100 g)	78.1	78	67	26	20	–
Niacin (mg/100 g)	0.5–0.7	5.5	5.4	1.8	1.9	3.6
β-Carotene (µg/100 g)	5,300	64	10	90	0	0

Source: refs. 13, 14, 20, 23, 24, 38.
a. – Trace or absent.

be a steroid or a triterpene, and the sugar moiety is generally glucose, galactose, pentose, or methyl pentose [59].

Seeds of *C. quinoa* variety Latinreco-40057, from the experimental farm of Latinreco, were found to contain two major saponins [38], whose structures are shown in figure 1. According to Mizui et al. [60], the chemical structures of saponins from quinoa brans are 28-O-β-glucopyranosyl-(1—>3)-α-arabino pyranoside, 3-O-β-glucopyranosyl-(1—>3)-β-galacto pyranoside, and 28-O-β-glucopyranosyl-(1—>3) esters of phytoaccagenic acid 3-O-α-arabino pyranoside.

Besides glycosides of oleonolic acid, 3-O-[(β-D_{20}-xylopyranosyl)(1—>3)-β-D-glucorono pyranosyl-6-OMe ester]-oleanoic acid has also been identified [61]. The other aglycons in the quinoa saponin mix have been identified as phyto laccagenic acid (> 40% total) and hederagenin (~26%) [62]. The saponin content has been correlated with that of oleanolic acid by an equation, saponin = 8.5204 oleanolic acid [63]. It can be determined by gas chromatography [64] and could serve as an index of saponin content. The results of a larva bioassay with *Tribolium castaneum* were correlated with the sapogenin content of seed flour [65].

Quinoa contains about 1.0% to 1.2% saponins [62], which are bitter [66] and have antinutritional effects. To be edible, quinoa grains must have the saponins removed, since they affect the colour and palatability of the products [67]. Saponins are located on the outer layers of the seeds and can be removed by polishing and washing with water. Reichert et al. [54] used abrasion milling to dehull quinoa and reduce the saponin levels. The amount of saponins present in quinoa differs according to the variety [63, 68]. Removal of saponins is associated with reduction in bitterness and astringency. As a result of sustained efforts in plant breeding, new low-saponin varieties of quinoa are available that afford better possibilities for use of the grain.

Quinoa saponins produce stable foams in aqueous solutions and haemolysed red blood cells. Because saponins form persistent foams in aqueous solutions, even

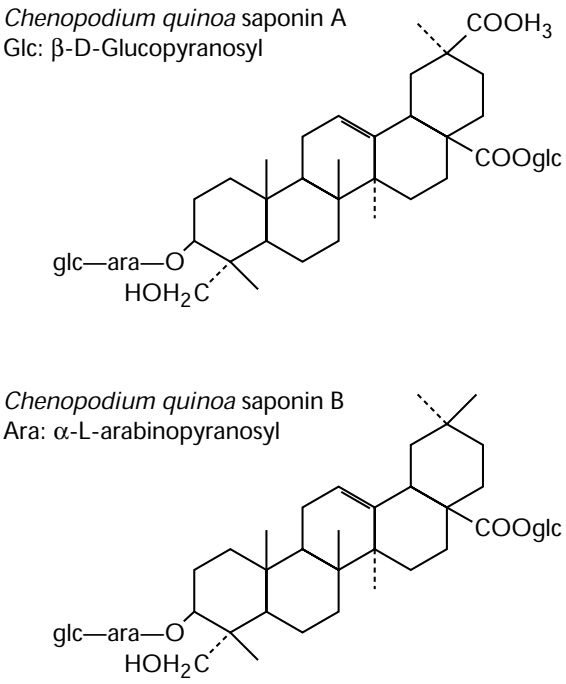

FIG. 1. Structures of quinoa (*Chenopodium quinoa*) saponins

at concentrations as low as 0.1%, they have found wide application in soft drinks, lager, shampoo, soaps, and fire extinguishers. They are prohibited as foaming agents in beverages and foods in Italy, Yugoslavia, and several countries of the Americas. Since they form permanent suspensions with oil powders, they are also used in the manufacture of confections and pharmaceuticals [56]. Saponins are known to have some beneficial effects on the skin and hence have been incorporated into toilet soaps, shaving soaps, and shampoos. The addition of saponins is found to lower the level of cholesterol in

plasma by increasing faecal bile excretion [69]. Saponins do not have any negative effect on the digestibility of proteins at the levels at which they are present in the samples [19]. Lopez de Romana et al. [70] reported better values for the digestibility of quinoa flour than of quinoa seeds. They concluded that quinoa proteins are adequate as human food. However, there is evidence that saponins from Chenopodiaceae inhibit growth in mice [71].

Since the commercial processing of quinoa yields a saponin-rich by-product, identifying possible uses for this material will be useful.

Phytic acid

Phytic acid is not only present in the outer layers of quinoa seeds, as in the case of rye and wheat [72], but is also evenly distributed in the endosperm. Ranges of 10.5 to 13.5 mg/g of phytic acid for five different varieties of quinoa were reported by Koziol [73], similar to the range of 7.6 to 14.7 mg/g for other cereals [74]. The phytates form complexes with minerals such as iron, zinc, calcium, and magnesium and can make the mineral content of a food inadequate, especially for children.

Tannins

The polyphenolic compounds, tannins, form complexes with dietary proteins and also with digestive enzymes [75]. The content of tannins measured as flavonols in whole raw quinoa seeds was 0.5%. Tannins were not detected in raw quinoa seeds that had been polished and washed [17] (table 11).

Protease inhibitors

The concentrations of protease inhibitors in quinoa seeds are less than 50 ppm [76]. It can be seen from table 11 that the trypsin inhibitor units of quinoa are much lower than those in commonly consumed grains and hence do not pose any serious concern.

Conclusions

Since the early 1970s, Peru, Bolivia, and Chile have shown an interest in quinoa grain. In 1980 Bolivia passed a law requiring the use of at least 5% quinoa flour in commercially produced bread, pasta, and other products. Chileans have been using quinoa to improve the nutrition of poor children, whereas in Peru an increase in quinoa production is seen as a means of reducing costly wheat imports. Quinoa-based infant food has been manufactured on a commercial scale. Commercial exploitation of quinoa in many regions of the world is still far from reality. However, its constituents, particularly starch, which forms the bulk of the seed and which can be obtained in a saponin-free form, could find applications in the food and the non-food industries. Low-fat, fried noodle-like snacks have been prepared from blends of quinoa starch and soya bean protein isolate. In these trials the efficacy of quinoa starch as compared with corn starch with respect to the oil content of the fried snacks was demonstrated [81]. These trials should pave the way for the use of quinoa grain in regions where the grain is cultivated but has yet to see any commercial exploitation.

TABLE 11. Antinutrient (saponins, phytic acid, and tannins) contents of quinoa seeds compared with those of other seeds

Seed	Antinutrient			
	Saponin (mg/g)	Phytic acid (mg/g)	Tannins (%)	Trypsin units inhibited (mg)
Quinoa				
Whole raw	9.0–21	10	0.5	1.4–5.0
Polished and washed raw	3.0			
Amaranthus paniculatas	Traces	5–6	0.04–0.13	0.5
Soya bean (*Glycine max*)	4–6	8	0.05	24.5–41.5
Kidney bean (*Phaseolus max*)	4	8–12	1.02	12.9–42.8
Lentils (*Lens esculenta*)	NA[a]	8	NA	17.8

Source: refs. 13, 17, 68, 77–80.
a. Not available.

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