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Applications of Quinoa (*Chenopodium Quinoa* Willd.) and Amaranth (Amaranthus Spp.) and Their Influence in the Nutritional Value of Cereal Based Foods

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Abstract The use of quinoa (*Chenopodium quinoa* Willd.) and amaranth (Amaranthus spp.) is of great nutritional interest because of their peculiar composition and the minor components present in these grains. In addition to being one of the important energy sources due to their starch content, these pseudocereals provide good quality protein, dietary fibre and lipids rich in unsaturated fatty acids. Also contain adequate levels of minerals, vitamins, and significant amounts of other bioactive components such as saponins, phytosterols, squalene, fagopyritols and polyphenols. Amaranth and quinoa are also gluten-free grains. This composition and nutritional facts describes their potential for functional properties (as supplements or common cereal replacers) and for human health, particularly for certain consumers such as the elderly, children, high-performance athletes, diabetics, celiacs, and people who are gluten or lactose intolerant among others. A review of the main aspects of amaranth and quinoa, and their food applications are presented here.

Keywords Gluten Free, Pseudocereals, Food Products

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) and amaranth (Amaranthus spp.) are indigenous pseudocereals domesticated from Andean region in South America and have potential agronomic importance across the world. These crops are highly nutritious and environmentally resistant. They can be adapted to different environmental conditions, being cultivated on poor soils and high altitudes[28],[51]. Quinoa and amaranth have potential as functional and bioactive ingredients in food products because their high dietary fiber content and natural antioxidants such as fenolic compounds [28]. These pseudocereals were important food crops in the Aztec, Mayan and Incan civilizations of the past and in recent years have attracted much interest to constitute an important part of the diet in Latin America, Africa, and Asia[4],[48]. Currently, amaranth and quinoa cultivation remains relatively low.

According to the FAOSTAT in 2009 the production of quinoa was 39.397 tonnes in Perú, 28.276 tonnes in Bolivia, and 746 tonnes in Ecuador[25]. Amaranth is not even listed in the FAO statistics on production data. Quinoa is also cultivated in Chile, USA (Colorado and California), China, Europe, Canada, and India, and experimentally in Finland and UK[1]. Besides Mexico and South American countries, the strongest interests in amaranth investigation and production have been present also in Europe, specially Austria, Czech Republic, Slovak Republic, Germany, Hungary, Poland, Russia, Italy, and Slovenia. Amaranth was introduced into Spain in the 16th century from where it had spread throughout Europe and around the early 19^{th} century it reached Africa and Asia. In the mid-1970s, the stimulus for the amaranth production and marketing in USA was initiated by the Rodale Foundation and the Rodale Research Center. In Asia and Africa amaranth is mainly planted as a vegetable plant, and has been maintained as a minor cereal food only in the Himalayan region of Asia[11],[57],[68]. In Brazil, in order to adapt these pseudo-cereals, experiments with quinoa have been conducted since 1987, with locally selected genotypes originating from hybrid populations. Since the mid 1990s works with the three main amaranth species were included. After many years of research *A. cruentus* BRS Alegria was the first cultivar recommended for the soil of the Brazilian cerrado[63],[64].

At present, consumption of alternative crops has attracted much interest as potential recipes for healthy food production and for special dietary uses. The opportunity to supplement or completely replace common cereal grains (corn, rice or wheat) with a higher nutritional value cereal (such as quinoa or amaranth) is becoming increasingly popular among people interested in improving and maintaining their health status by changing dietary habits.

The aim of this review is to provide the main aspects of

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amaranth and quinoa and their applications in food products.

2. Characteristics of the Grains

Pseudocereals are dicotyledonous species which are not closely related to each other or to the true cereals monocotyledonous (e.g. wheat – *Triticum* spp., rice – *Oryza sativa*, barley – *Hordeum vulgare* L.)[4],[7],[30],[39],[50],[59],[69]. The name pseudocereal derives from their production of small grain-like seeds that resemble in function and composition those of the true cereals. This group comprises three crops, amaranth spp., quinoa and buckwheat (*Fagopyrum esculentum*, Polygonaceae). All of them contain main major groups of 11S globulin storage proteins, smaller amounts of 2S albumins, and 7-8S globulins, which appear in buckwheat and amaranth[30].

Botanically quinoa belongs to the class Dicotyledoneae, family *Chenopodiaceae*, genus *Chenopodium*, and specie *quinoa*. The full name *Chenopodium quinoa* Willd. includes the author abbreviation corresponding to Carl Ludwig Willdenow. The genus *Chenopodium* includes approximatel y 250 species both domesticated and free-living weedy forms[1],[69]. Among quinoa sweet and bitter varieties exists dependent on the content of saponins (i.e. the variety is considered to be a sweet variety if the saponin content is below 0.11 %)[37].

Amaranth belongs to the order *Caryophyllales*, family *Amaranthaceae*, genus *Amaranthus*, and section *Amaranthus[*11],[57]. The genus *Amaranthus* includes about 60 species, most of which are cosmopolitan weeds associated with difficulties in cultivation practices after soil disturbance and seed exposure to light[11],[30]. The three principal species of genus *Amaranthus*, originating in South America and considered for grain production are: *A. hypochondriacus* L. (México), *A. cruentus* L. (Guatemala), and *A. caudatus* L. (Peru and other Andean countries)[11],[13],[57].

The grain structure of amaranth and quinoa differ significantly from cereals such as maize (*Zea mays*) and wheat. Amaranth seeds are small (0.9 to 1.7 mm diameter) with 1000-seed weights from 0.6 to 1 g, they are lenticular in shape and the colour varies from white, gold, brown and pink to black[13],[30]. Quinoa seeds (1-2.6 mm diameter) with about 350-seeds weigh 1 g are round, flattened, and oval-shaped, and with colors ranging from pale yellow to pink or black[1],[53],[65].

In amaranth and quinoa seeds, the embryo or germ is campylotropous and surrounds the starch-rich perisperm like a ring and together with the seed coat represent the bran fraction, which is relatively rich in fat and protein [13],[33],[47],[59],[65]. The percentage of bran fraction is higher in amaranth and quinoa seeds in comparison with common cereals, which explains the higher levels of protein and fat present in these seeds[13]. In amaranth the seed coat is smooth and thin, thus it is not necessary to remove it[11],[33]. In quinoa the pericarp contains saponins which transmit the bitter taste characteristic[69]. The main seed storage tissue is perisperm (diploid in chromosome number), and not endosperm which is present only in the micropylar region of the seed[33],[47].

3. Nutritive Value

3.1. Proteins and Amino Acids

The nutritional value of pseudocereals is mainly connected to their proteins that are an important group of biomacromolecules involved in physiological functions[29]. According to the literature, the protein content is 14.0 - 16.5% for amaranth and 12.9 - 16.5 % for quinoa (Table 1)[3],[36],[59]. Compared with common cereals grains, the protein content (average of 14.60 % and 13.80 % respectively) is significantly higher than that of maize (10.20 %), and comparable to that of wheat (14.30 %). Amaranth and quinoa contain relatively minor protein content when compared with legume seeds such as bean (*Phaseolus vulgaris*) (28.0 %) or soya (*Glycine max*) (36.1 %)[36].

In pseudocereals, most of the protein is located in the embryo[69] and contrarily to common grains such as wheat, the proteins are composed mainly of globulins and albumins, and containing very little or no storage prolamin proteins, which are the main storage proteins in cereals and the toxic proteins in celiac disease[4],[30],[69]. Because the very little or no prolamin content, quinoa and amaranth are considered to be a gluten-free grains. Amaranth proteins consist of about 40 % albumins, 20 % globulins, 25 - 30 % glutelins, and 2 – 3 % prolamins[59].

Two main classes of globulins can be differentiated in amaranth: 7S (conamaranthin) and llS (amaranthin) storage globulins[42],[43]. Moreover, in quinoa the two major classes of proteins are 11S (chenopodin) with 37 % of total protein, and 2S (highcysteine) with 35 % of total protein[14]. However, the importance of proteins in these pseudocereal species is also based on their quality. The protein nutritional quality is determined by the proportions of essential amino acids, which cannot be synthesized and hence must be provided in the diet. If one of these essential amino acids is limiting, the others will be broken down and excreted, resulting in poor growth and loss of nitrogen in the diet[70].

The amino acid composition of globulins and albumins differs significantly to that of prolamins. They contain less glutamic acid and proline than prolamins, and more essential amino acids such as lysine, methionine + cystine, and histidine (Table 2), resulting in a well-balanced amino acid composition for pseudocereal proteins[29],[36]. Lysine content for quinoa and amaranth is about twice as high as in other common cereals such as wheat or maize. Also quinoa presents higher histidine content than maize or wheat. In comparison with the FAO/WHO reference pattern suggested for preschool children, quinoa presents the best amino acid profile, since there is no deficiency of any essential amino acid. Quinoa presents high levels of histidine, isoleucine, and aromatic amino acids (phenylalanine and tyrosine) and has similarly in leucine and tryptophan contents. When compared to the requirements in school children and adults, quinoa protein can supply more than 150 % the requirements of school children and more than 200 % of adults.

Amaranth protein shows an excellent amino acid pattern; although some amino acids such as leucine are present in amounts slightly lower than those recommended, suggesting that it could be necessary the combination of amaranth with any other cereals to reaches the recommended requirements [10],[30],[59]. Regarding to the FAO/WHO, they suggested preschool requirements, amaranth protein have adequate levels of tryptophan, histidine, valine, phenylalanine, lysine and threonine. Some authors indicate leucine as the limiting amino acid in amaranth when the chemical score is considered[10]. However, still as a limiting amino acid in the chemical score, leucine can supply between 60 % and 95 % preschool requirements.

The high bioavailability of pseudocereal′s protein has been shown in several studies[27],[36],[52]. Reference[50] studied the nutritional quality of protein in quinoa and concluded that it equals that of casein. In addition, many studies have shown that protein quality can also be affected by processing. Reference[31] reported a high protein efficiency ratio (PER) and a high apparent digestibility for washed and cooked quinoa, concluding that the quality of quinoa protein equals that of casein. Also the authors concluded that the slightly lower PER of amaranth may be due to a lower isoleucine content and apparent digestibility of the protein. Reference[53] showed that quinoa protein digestibility is increased when an adequate heat treatment is applied. Reference[27] observed that lysine was the limiting amino acid in popped samples of amaranth. They also observed a high loss of tyrosine followed by phenylalanine and methionine.

3.2. Carbohydrates and Starch

Carbohydrates are components that contribute 50 - 70% of dietary energy and are classified according to their degree of polymerization into three principal groups: sugars (monosaccharides, disaccharides, polyols), oligosaccharide, and polysaccharides (starch and nonstarch)[20].

Amaranth and quinoa carbohydrates can be considered nutraceutical foods because they have hypocholesterolemic effects[22],[49], beneficial hypoglycemic effects, and induce lowering of free fatty acids[12]. In addition, as gluten free-foods, quinoa and amaranth can be recommended for people with celiac disease[12]. Reference[12] also observed that in individuals with celiac disease the glycemic index of quinoa was slightly lower than that of gluten-free pasta and bread. Besides, quinoa induced lower free fatty acid levels with respect to gluten-free pasta and significantly lower triglyceride concentrations than gluten-free bread.

Starch is the most important carbohydrate in all plants and occurs typically as granular form of various shapes and sizes. Starches from amaranth and quinoa have been studied since the early 1980s with respect to isolation methods, physical, functional and macromolecular properties[48].

In amaranth, starch comprises the main component of carbohydrates, but is found usually in lower amounts than in cereals (Table 1). Amaranth starch is located in the perisperm (Figure 1), where typical compounded starch particles that can reach a length of 90 µm in diameter are generated in the amyloplasts. After the mixture in cold water, small single polygonal starch granules of 1-3 µm in diameter can be extracted from these agglomerates[19],[59].

Table 1. Chemical composition of quinoa and amaranth and comparison with that of some cereals and legumes (average value in %, range in brackets)

	Chenopodium quinoa [a]	*Amaranthus* spp.[a]	Maize [b]	Wheat [b]	Soya [b]
Protein	13.80 (12.9[c] - 16.5[b]) [*]	14.60 (14.0[g] - 16.5[d])	10.2	14.3	36.1
Fat	5.04 (5.2[d] - 9.7[e])	8.81 (5.7[d] -10.9[g])	4.7	2.3	18.9
Carbohydrate	69.00[b] (61.2[f] - 72.6[e])	-- (68.8[h] - 70.3[d])	81.1	78.4	34.1
Starch	67.35 (51.6 - 64.2[d])	55.10 (61.4[d] - 65.8[g])			
Crude fiber	2.30 (1.8[f] - 2.2[f])	3.9			
Dietary fiber	12.88 (13.3[d] - 14.2[d])	11.14 (12.0[d] - 20.6[d])			
Ash (minerals)	3.33 (2.7[d] - 3.8[b])	3.25 (2.4[g] - 3.8[i])	1.7	2.2	5.3
kcal/100g	399[b]		408.0	392.0	451.0

Average value as reported by [a][59] (protein: N x 5.8) and [b][36], based in dry basis (protein: N x 6.25).
[*]The range given in brackets represents the range from the lowest to the highest value given in the literature:
[c] Data according to[7], based in dry basis (protein: N x 6.25).
[d] Data according to[3], based in dry basis (protein: N x 5.85).
[e] Data according to[52], based in dry basis.
[f] Data according to[17], based in dry basis.
[g] Data according to[46], based in dry basis (protein: N x 6.25).
[h] Data according to[31], based in dry basis (protein: N x 6.25).
[i] Data according to[10], based in dry basis (protein: N x 5.85).

Table 2. Comparison of essential amino acids content of quinoa, amaranth, maize and wheat to FAO/WHO suggested requirements

	Quinoa[a]	*Amaranthus*[b] spp.	Maize[a]	Wheat [a]	FAO/WHO suggested requirements[a]		
Amino acids	($g\ 100\ g^{-1}$ protein)				Preschool	School children	Adults
Histidine	3.2	2.5 - 3.0[c]	2.6	2.0	1.9	1.9	1.6
Isoleucine	4.4	2.7 - 4.1	4.0	4.2	2.8	2.8	1.3
Leucine	6.6	4.2 - 6.3	12.5	6.8	6.6	4.4	1.9
Lysine	6.1	5.1 - 6.1	2.9	2.6	5.8	4.4	1.6
Methyonine + Cystine	4.8	4.1 - 4.9	4.0	3.7	2.5	2.2	1.7
Phenylalanine + Tyrosine	7.3	6.0 - 8.5	8.6	8.2	6.3	2.2	1.9
Threonine	3.8	3.3 - 4.0	3.8	2.8	3.4	2.8	0.9
Tryphtophan	1.1	0.9 - 1.82	0.7	1.2	1.1	0.9	0.5
Valine	4.5	3.9 - 4.7	5.0	4.4	3.5	2.5	1.3

[a] Data according to[36].
[b] Data according to[30].
[c] Data according to[23].

Table 3. Fatty acid composition of fat in amaranth, quinoa, wheat and maize seeds (g/100g)

Fatty acid	Quinoa [abc]	Amaranth[bde]	Wheat[b]	Maize[c]
Myristic acid (C14:0)	0.1	-	-	0.2
Palmitic acid (C16:0)	9.7 - 11.0	12.3 - 20.9	23.7	11.2
Stearic acid (C18:0)	0.6 - 1.1	3.1 - 4.1	2.8	2.1
Oleic acid (C18:1)	24.5 - 26.7	23.7 - 32.9	13.2	29.8
Linoleic acid (C18:2)	48.2 - 56.0	47.5 - 47.8	55.1	55.0
Linolenic acid (C18:3)	3.8 - 8.3	0.9	3.8	0.9
Arachidic acid (C20:0)	0.4 - 0.7	0.4 – 1.5	0.3	0.4
Eicosenoic acid (C20:1)	1.4	-	-	-.
Eicosadienoic acid (C20:2	0.1 - 1.4	0.3	0.5	-
Behenic acid (C22:0)	0.5 - 0.7	0.1 - 0.8	0.2	-
9-Docosenoic acid (C22:1w9)	1.2 - 1.5	n.d.	n.d.	-
Tetracosanoic acid (C24:0)	0.2 - 0.4	0.4 - 0.8	n.d.	-.
Tetracosaenoic acid (C24:1)	2.4 - 2.6	-	-	-
Saturated	14.0	20.9 - 26.9	27.3	-
Monounsaturated	28.1	23.9	13.4	-
Polyunsaturated	57.5	49.1	59.4	-
Unsaturated/saturated	4.9 - 6.2	2.7 - 3.7	2.7	-
Linoleic/ α-linolenic	5.8 - 13.8	52.4	14.5	-
Total C18 *trans*	0.1	0.2	0.0	-

[a] Data according to[53].
[b] Data according to[3].
[c] Data according to[37].
[d] Data according to[15].
[e] Data according to[23].
n.d, not detected

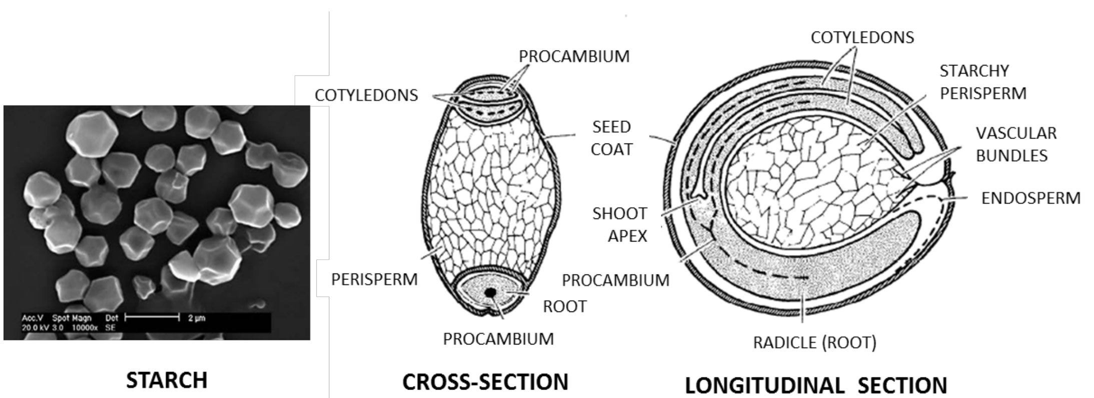

Figure 1. Starch and illustration of amaranth (*Amaranthus* spp.) seed in cross and longitudinal section. Adapted from[33], and[35]

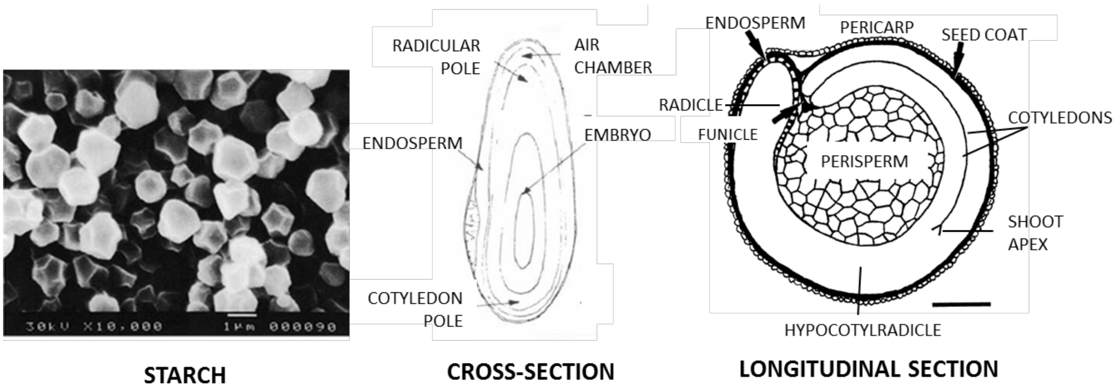

Figure 2. Starch and illustration of quinoa (*Chenopodium quinoa* Willd.) seed in cross and longitudinal section. Adapted from[7],[26] and[47]

In quinoa, as in amaranth, the starch is also located in the perisperm with small amounts occurring in the seed coat and embryo[47]. The single polygonal grains, similar to that of amaranth, vary in diameter from approx. 0.08 to 2.5 µm[7],[8]. Compound structures, consisting of oblong or spheroidal aggregates of simple grains, can reach a length of 80 µm and are surrounded by a protein matrix[8].

The amylose content of amaranth starch is lower than that in other cereal starches, with values varying from 0.1 % to 11.1 %[59]. Physical properties such as freeze-thaw and retrogradation stability, lower swelling power and amylograph viscosity, higher solubility and gelatinization temperature range, higher sorption capacity at high water activity range, higher solubility, swelling power, water-binding capacity, and enzyme susceptibility [9],[10],[19],[59], can be explained by the small size of the starch granule as well as its high amylopectin content. However, when selecting genotypes for particular processing purposes, it need to be taken into account the genetic diversity in physical properties of starch and variations in the other constituents (proteins, lipids, minerals), which have an influence on starch functional properties within and among amaranth species[30].

The amylose content of quinoa starch can be found in different amounts, ranging from 3.5 to 22 %[39],[48],[59]. This wide variation within the amylose content is therefore responsible for the differences in physical properties of starch[59]. The quinoa starch exhibits lower gelatinization temperatures, and higher viscosity and solubility than amaranth starch, high water-binding capacity, high swelling power, high enzyme susceptibility, and excellent stability under freezing and retrogradation processes[8],[48],[59].

Dietary fiber is known to have beneficial effects on human health. The fiber content of amaranth and quinoa lies within the range of other cereals. The fraction of dietary fiber for amaranth varies between 11.14 and 20.6 %, indicating a high variation within different species (Table 1). The dietary fiber content of quinoa (12.88-14.20 %) is present especially in the embryo. Reference[22] examined the effects of dietary amaranth fiber on serum and liver lipids in male rats receiving cholesterol-supplemented diets providing approximately 8 % dietary fiber. Amaranth resulted in lower serum cholesterol values than those of fiber-free controls and lower liver cholesterol values than those of cellulose. In the colon, amaranth acted like cellulose (a poorly fermented fiber). This study suggests that amaranth behaves like soluble fibers in lowering serum cholesterol but like insoluble fibers in terms of its action in the colon. According to[54] the proportion of quinoa soluble fiber can be decreased by cooking and autoclaving processes, while the insoluble fractions do not differ.

3.3. Lipids

The lipid content of quinoa and amaranth is between 2 and 3 times higher than in other cereals such as maize and wheat (Table 1)[4],[36],[59]. Quinoa fat content (ranges from 5.2 to 9.7 %) is higher than maize (4.7 %) and lower than soy (18.9 %)[37],[52],[59]. Amaranth grain has higher lipid content than quinoa and most other cereal grains, and it is present between 5.7 % and 10.9 % (average 8.81 %) (Table 1)[3],[59].

The fatty acid composition in quinoa and amaranth compared with some cereals such as wheat and maize is presented in Table 3. Because a fatty acid profile similar to that of maize oil and soybean oil, quinoa has been considered an alternative oilseed crop[36],[37]. The oil present in amaranth shows interesting chemical characteristics for potential use as nutraceutical[15]. From the given data it can be observed that quinoa and amaranth seeds, including wheat seeds, are rich in unsaturated fatty acids, with the highest unsaturated/saturated ratio observed from quinoa (4.9 – 6.2).

Amaranth and quinoa lipids present a high degree of unsaturation. In quinoa seeds only 14.0 % of fatty acids are saturated. According to[23],[30] and[59], in amaranth oil, between 75 - 77.1 % of fatty acids are unsaturated. Linoleic acid is the most abundant fatty acid (47.5 - 47.8 and 48.2 - 56.0 for amaranth and quinoa respectively), followed by oleic acid (23.7 – 32.9 in amaranth and 24.5 - 26.7 in quinoa) and palmitic acid (12.3 - 20.9 in amaranth and 9.7 - 11.0 in quinoa)[3],[15],[53]. Quinoa shows a high content of α-linolenic acid (values ranging from 3.8 % to 8.3 %) which is related to a reduction of biological markers associated with many degenerative diseases such as cardiovascular disease, cancer, osteoporosis, and inflammatory and autoimmune diseases[62].

Despite their high fat content and degree of unsaturation, amaranth and quinoa lipids are reported to be generally stable against oxidation. This property has been attributed to the natural presence of a high amount of vitamin E (α-tocopherol) who acts as a natural defense against lipid oxidation and thus increases the stability of the oil[36],[59].

3.4. Vitamins

The vitamin composition of quinoa is similar to that of cereals[65] containing significant amounts of thiamin (0.29 - 0.36 %), riboflavin (0.30 - 0.32 %), vitamin B6 (0.487 %) and folate total (0.18 %). Amaranth also is a good source of riboflavin (0.19 - 0.23 %) and ascorbic acid (4.50 %) (Table 4). Compared with barley, niacin values are lower in both pseudocereals (4.604 % of niacin present in barley). Reference[10] analysed some amaranth samples for ascorbic acid content and found amounts ranging from 3.36 to 7.24. In quinoa seeds, ascorbic acid can be found in levels varying from 4.0 to 16.4 mg/100 g[36],[53]. Furthermore amaranth and quinoa are excellent sources of vitamin E, which contributes to the prolonged stability of the oil. Tocopherols, the major vitamers of vitamin E, are fat-soluble antioxidants that act as scavengers of lipid peroxyl radicals[55]. Among the tocopherols, in amaranth, α-tocopherol is the most abundant and was found in amounts of 248 mg/kg amaranth oil. It was also found a high concentration of β-tocopherol (546 mg/kg amaranth oil)[38]. Quinoa seeds contain twice as much γ-tocopherols (5.3 mg/100 g) as α-tocopherols (2.6 mg/100 g)[53].

Table 4. Vitamin composition in quinoa, amaranth and barley (mg/100g dry weight)

Vitamin	Quinoa[a] flour	Amaranth [b] flour	Barley[a]
Thiamin (B1)	0.29 - 0.36	0.07 - 0.10	0.191
Riboflavin (B2)	0.30 - 0.32	0.19 - 0.23	0.114
Niacin (B3)	1.24 - 1.52	1.17 - 1.45	4.604
B6	0.487	-	0.260
Folatetotal	0.18	-	0.023
Ascorbic acid (C)	-	4.50	-
β-carotene	-	0	-

[a] Data according to[1].
[b] Data according to[10].

3.5. Minerals

Variations in mineral content are influenced by environmental conditions during plant growth and seed set, especially in soil mineral availability[3]. Table 5 shows the mineral content of amaranth and quinoa. Calcium, magnesium and iron are minerals that are deficient in gluten-free products and in the gluten free-diet. The inclusion of these pseudocereals, which are a good source of these and other important minerals, can assist to reduce this deficiency[4]. In general, the content of minerals in amaranth and quinoa is about twice as high as in other cereals. In both of pseudocereals, calcium, magnesium, iron, and zinc can be found in high amounts when compared with wheat or barley. In amaranth seeds the high calcium content (180.1-217.0 mg/100 g) is of special relevance in relation to the well known prevalence of osteopenia and osteoporosis among newly diagnosed celiac patients[3],[4]. The content of calcium in quinoa can contribute 10 % of the infant and adult requirements[1].

Through removal of saponins (mechanically and/or through washing) the mineral content of quinoa can be strongly reduced. This loss is considerable in the case of some minerals such as iron, manganese and potassium (e.g. 46% of the potassium can be lost)[53].

3.6. Other Bioactive Components

Squalene, a highly unsaturated open-chain triterpene, which is the biochemical precursor of the whole family of steroids is present in high levels in amaranth (1.9 to 11.19 %)[34],[49]. References[34] and[55] also found 3.39-5.84 % of squalene in the lipid fraction of quinoa seed. These levels are higher if considering the amount present in other plant oils such as olive oil, wheat germ oil, rice bran oil and yeast (0.1-0.7 %)[10]. As a food constituent, squalene presents the ability of inhibit the cholesterol synthesis in the liver lowering the cholesterol levels[49],[60]. Reference[60] observed that amaranth squalene exerts a cholesterol-lowering effect by increasing fecal elimination of steroids through interference with cholesterol absorption. This compound is principally used as an oxidation-resistant industrial lubricant, as an intermediate in many pharmaceuticals, organic colouring materials, rubber chemicals, and as a bactericide [2],[11],[59].

Table 5. Mineral composition in quinoa, amaranth, wheat and barley (mg/100 g dry-weight basis)

Mineral	Quinoa seed[ab]	Amaranth (seed)[a]	Wheat[a]	Barley[c]
Calcium (Ca)	32.9 - 874.0	180.1 - 217.0	34.8	29.0
Iron (Fe)	5.5 - 81.0	9.2 - 21.0	3.3	2.5
Magnesium (Mg)	206.8 - 2 620.0	279.2 - 319.0	96.4	79.0
Zinc (Zn)	1.8 - 36.0	1.6 - 3.4	1.2	2.1
Manganese (Mn)	33.0	-	-	-
Potassium (K)	1 201.0	-	-	-

[a] Data according to[3].
[b] Data according to[53].
[c] Data according to[1]

Squalene and phytosterols are components present in the unsaponifiable lipid fraction of foods (as tocopherols). Phytosterols which are natural components of plant cells are abundant in vegetable oils, seeds, and grains, have antiinflammatory effects, antioxidative and anticarcinogenic activity, and cholesterol-lowering capacity[1],[44],[55]. Reference[55] reported higher levels of β-sitosterol (63.7 mg/100 g), campesterol (15.6 mg/100 g), and stigmasterol (3.2 mg/100 g) in quinoa seeds, which are higher than in barley, rye, millet and maize, but lower than in lentils, chick peas, or sesame seeds. In amaranth, besides the remarkable abundance of squalene (approximately 80 % of the entire unsaponificable fraction), chondrillasterol proved to be the predominant sterol present[15]. Among the seven sterols identified in quinoa lipids, Δ^7-stigmasterol is the major one[2].

Quinoa seeds are also an abundant source of flavonoids. The main polyphenols present in quinoa are kaempferol and quercetin glycosides. In amaranth, polyphenols can be found in amounts ranging from 14.72 to 14.91 mg/100g[59]. Tannins are polyphenolic secondary plant metabolites of higher plants, which can be found in high concentrations in the hulls of cereals and legumes[59]. Reference[10] evaluated 10 different samples of amaranth and found a range of 80-420 mg/100 g of tannins. Also values of tannin contents varying from 0 to 500 mg/100 g, in quinoa, have been reported[17],[59].

4. Utilization and Applications

Amaranth and quinoa grains have been used in a wide variety of foods. From the whole grain, tasteful soups, sweets, beverages, sauces, porridges, and soufflés can be prepared; boiled grains can be used as rice. Various hot or fermented drinks can also be produced. The grains are germinated for sprouts and malted for beer production. The fermented beverage made from amaranth and quinoa seeds are called *chicha[*24]. Quinoa is used frequently to prepare coarse bread called *kispina[*41]. They also serve as starchy material, and protein concentrates, and flours can be produced. Amaranth grain rolled or popped can be used in breads, muesli and in granola bars. Grain can be ground and used as a flour ingredient in different mixtures for pancakes, breads, muffins, crackers, dumplings, cakes, cookies, *pasta*, puddings, etc[5],[24],[27],[30],[41],[54],[58].

Among cereals only wheat has the ability to form strong and cohesive dough, capable to retain gas and of giving spongy product for cooking. Gluten is the wheat protein believed to be responsible for the unique viscoelastic texture of wheat flour dough, which enables the formation of foam-like bread through its expansion by yeast fermentation[65]. Proteins of other cereal grains, are not supposed to be capable of forming dough. Then, mixtures of wheat flour and other cereals are used in order to obtain bakery products.

At the moment, amaranth and quinoa are potential sources of food due to their high quality of proteins[31]. The amount of high-protein possessing an attractive amino acid balance for human nutrition because of it high levels of lysine and methionine represents a compromise between nutritional improvement and achievement of satisfactory sensory and functional properties of the product. The main problem in the use of quinoa and amaranth as components, replacing wheat in the blends, arises from the fact that these pseudocereals do not contain gluten, and thus the addition into leavened and pasta products are limited[30]. Hence, when amaranth and quinoa flours have been used to make leavened bread they have usually been used as composite with wheat flour[65].

4.1. Application of Amaranth and Quinoa in Composite Flours

Composite flour technology refers to the process of mixing wheat and non-wheat high protein components or use of non-wheat mixtures (roots and tubers, legumes, etc) in bread making, baking goods and pasta products[30].

Composite flour bakery products have many advantages. Apart from extending the availability of wheat flour, they are looked upon as carriers of nutrition improving the diet. Also the use of locally grown non-wheat cereals or millets, not only give the value addition but also provide the avenue for local taste[61]. Several works have been made to investigate new applications of amaranth and quinoa seeds in various food products as it can act as promising foods on the account of its nutritional qualities and to complement other cereals as supplements for adding nutritional value [17],[21], [40],[45],[51],[61].

Reference[51] investigated the effect of wheat flour replacement at different levels (from 0 up to 100%) by flours from quinoa, kañiwa (*Chenopodium pallidicaule*), amaranth and tarwi (*Lupinus mutabilis*) in wheat doughs and fresh bread quality. No breads with aerated crumb structure were obtained from 100 % Andean crop flours with the exception of quinoa breads that deserved overall sensory with no significant differences with respect to the breads made from the blends wheat:quinoa (50:50). Also replacement of wheat flour by up to 50 % of amaranth led to coloured breads with good sensory perception. The dough mixing and breadmaking properties of quinoa-wheat flour blends containing from 0 to 20 % (in 5 % increments) of manually dehulled quinoa meal or flour were evaluated by[18]. They observed that dough development time increased with increase in meal but decreased with increase in quinoa flour. An evaluation by a panel suggested a potential inclusion of 10 % flour or water extracted meal.

Some characteristics of dough and bread containing quinoa flour were studied by[45]. The substitution of 7.5 to 10 % of quinoa flour for hard-type wheat flour increased significantly the loaf volume of bread, but more than 15 % substitution distinctly decreased it. A combination of microbial lipase and 15 % substitution of quinoa flour improved the bread qualities with a loaf volume distinctly higher than that of the control and also suppressed the staling of bread during storage.

Also, the use of quinoa in mixtures with corn for extrusion has been studied by[21]. 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. Quinoa addition produced unprocessed and extruded products higher in protein, fiber, ash and some amino acids than 100% corn grit products. Products containing quinoa presented greater nitrogen solubility and a somewhat lower in-vitro digestibility than the products containing only corn grits. Also they observed that the most favorable products presenting the greater expansion, were produced at a 15 % initial moisture content. Sensory evaluation of the end products indicated a good consumer acceptance.

In the research of[40] the bread making potential of wheat-amaranth composite flours were discussed. Increasing levels of amaranth flour substitution (from 0 to 20 %, in 5 % increments) increased the proofing times while specific volumes and total scores of the breads decreased. Breads baked with flour milled from seeds of amaranth had lower volumes and lower total scores at wheat flour substitution level of 10 % or higher. The flavor of the bread was described as nutty and was preferred over the flavor of the white bread control. Replacement of 15 and 20 % of wheat flour resulted in darker bread crumb measured by Hunter colour difference meter and evaluated as questionable by panel one day after baking. The research of[67] with whole and defatted hyperproteic amaranth flours, reported a gradual decrease in volume and specific volume with respect to control breads at increasing substitution levels for both amaranth flours. Also a deleterious effect was noticed in the bread score values. The hyperproteic whole amaranth flour, due to the presence of oil, presented a better performance and can substitute up to 8 % wheat flour without severe modifications in bread quality and acceptance. An increase of substitution levels up to 8 % for hyperproteic defatted amaranth flour and up to 12 % for hyperproteic whole amaranth flour produced an unacceptable detrimental effect in bread quality revealed by scoring. Increased level of amaranth flour in the mixture enhanced protein quality increasing almost twofold the lysine concentration for acceptable breads.

4.2. Application in Gluten-Free Cereal Based Foods

Also the application of amaranth and quinoa in gluten-free products has been studied. The gluten-free products currently available in the market are considered of low quality and poor nutritional value[3]. The fact that amaranth and quinoa do not contain gluten could be advantageous for people suffering from celiac disease and wheat allergy or intolerance[65]. In this way, there is an increasing interest in their application in the production of nutrient-rich gluten-free products. There are many studies in the area of gluten-free cereal-based products which have mainly concentrated on the improvement of the structural properties and also in the viability of pseudocerals such as amaranth, quinoa and buckwheat as ingredients in gluten-free breads, crackers, biscuits and pastas with the aim of improving the nutritional quality of these products[3],[5],[16],[32],[45],[58],[66].

In recent studies[3] and[5] assessed the baking properties and their potential as healthy and high-quality ingredients in gluten-free breads. The authors found that the replacement of potato starch with a pseudocereal flour resulted in gluten-free breads with significantly higher levels of important nutrients such as protein, fiber, calcium, magnesium, zinc, iron and vitamin E. The resultant breads also had higher content of polyphenol compounds especially for buckwheat, another pseudocereal, and quinoa. The antioxidant capacity was significantly increased[6]. Bread volumes were found to significantly increase for buckwheat and quinoa breads in comparison with the control, and all the pseudocereal-containing breads were characterized by a significantly softer crumb structure. Finally, no significant differences were obtained in the acceptability of the pseudocereal-containing gluten-free breads in comparison with the control[5]. Reference[56] formulated products (cakes and fillings for chocolate and bakery products) with functional characteristics, adding nutritional value, using quinoa as one of the main ingredient because its high content of nutrients and to be free of gluten. The application of quinoa and corn mixtures in the production of a gluten-free spaghetti-type product was studied by[16]. Parameters such as cooking quality, texture and viscosity were determined. The spaghetti had reasonable physical properties in comparison to soft wheat spaghetti. A sensory panel was also conducted and the products were found to have a meliorated corn taste, which was well accepted. Reference[66] used whole amaranth flour to develop gluten-free biscuits with higher protein content. The authors also found that the addition of 0.1 % butylated hydroxytoluene (BHT) extended the shelf-life without affecting the flavor.

Also[32] presented some results from the evaluation of microbiological, nutritional and sensory values of gluten-free biscuits and crackers made with amaranth flour. These products with a high protein and energy value were recommended as dietetic complements to expand and enrich the assortment not only for a gluten-free diet but also for other market consumers.

Reference[58] investigated the use of amaranth, quinoa and buckwheat for the production of gluten-free pasta with good textural quality, in particular, low cooking loss, optimal cooking weight and texture firmness. Amaranth showed least suitability for pasta production as it lowered texture firmness and decreased cooking time and cooking tolerance. Pasta from quinoa were better agglutinated, but showed increased cooking loss. A combination in optimal levels of the three pseudocereal flours, albumen, emulsifiers, and enzymes improved the physical properties to obtain a high quality pasta product. However, differences in terms of color, elasticity and sensory properties were observed.

5. Conclusions

Amaranth and quinoa are plants originated in the Andean region and have been gaining potential agronomic importance across the world. These pseudocereals are recognized as potential food sources because their high content and quality of proteins. Amaranth and quinoa proteins are 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. They also have functional and bioactive ingredients such as dietary fiber, polyunsaturated fatty acids with good stability, and natural antioxidants such as phenolic compounds. Their variable applicability in foods includes items like bread, biscuits, cakes and pasta which are the most consumed and therefore appropriate carriers for protein enrichment. Because their low or no content of gluten, the main protein present in most common cereals, these pseudocereals can be considered as gluten-free products and being suitable for incorporation into the diet for celiac disease patients.

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