CHAPTER 1

Quinoa (*Chenopodium quinoa* Willd.): Composition, Chemistry, Nutritional, and Functional Properties

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Contents

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Abstract Quinoa (*Chenopodium quinoa* Willd.), which is considered a pseudocereal or pseudograin, has been recognized as a complete food due to its protein quality. It has remarkable nutritional properties; not only from its protein content (15%) but also from its great amino acid balance. It is an important source of minerals and vitamins, and has also been found to contain compounds like polyphenols, phytosterols, and flavonoids with possible nutraceutical benefits. It has some functional (technological) properties like solubility, water-holding capacity (WHC), gelation, emulsifying, and foaming that allow diversified uses. Besides, it has been considered an oil crop, with an interesting proportion of omega-6 and a notable vitamin E content. Quinoa starch has physicochemical properties (such as viscosity, freeze stability) which give it functional properties with novel uses. Quinoa has a high nutritional value and has recently been used as a novel functional food because of all these properties; it is a promising alternative cultivar.

I. INTRODUCTION

Quinoa is one of the seeds considered as pseudocereals; it is a broadleaf plant that has been used like the cereals. This crop was an important food for the Incas and still remains as an important food crop for the Quechua and Aymara peoples of the rural regions. A native of the Andes, quinoa dates back more than 5000 years. It was called ''the mother grain'' by the Incas; it sustained the Inca community and was considered sacred. This seed was the major crop of the pre-Columbian cultures in Latin America. After the arrival of the Spaniards, its use, consumption and cultivation was almost eliminated and only remained in the farmers' traditions. Quinoa grains have an established excellent nutritional food quality, and that is the reason for the great recent interest in it. Botanically, quinoa belongs to the class Dicotyledoneae, family Chenopodiaceae, genus *Chenopodium*, and species *quinoa*. The full name *Chenopodium quinoa* Willd. (Marticorena and Quezada, 1985; Winton and Winton, 1932) includes the author abbreviation corresponding to Carl Ludwig Willdenow. The species *Chenopodium quinoa* Willd. includes both domesticated and free-living weedy forms (Wilson, 1981, 1988).

Chenopodium species are used either as whole plants or parts of the plant. There is great diversity in plants and inflorescences (Mujica and Jacobsen, 2006). The genus Chenopodium includes about 250 species (Bhargava *et al.*, 2005). Quinoa is an annual plant found in the Andean region of South America, between sea level and the heights of the Bolivian Altiplano at around 4000 m above sea level. It produces flat, oval-shaped seeds that are usually pale yellow but can range in color from pink

to black. The adaptation of certain quinoa varieties is possible even under marginal environments for the production of seeds with high protein and mineral content (Karyotis *et al.*, 2003). Quinoa's aptitude to produce high-protein grains under ecologically extreme conditions makes it important for the diversification of agriculture as in high-altitude regions of the Himalayas and North Indian Plains (Bhargava *et al.*, 2005). Quinoa is reported to be one of the few crop plants grown in the salt level of southern Bolivia and northern Chile (Jacobsen *et al.*, 2000; Tagle and Planella, 2002). Salinity influences plant growth, seed yield, and seed quality even of halophytic crops such as quinoa. Plant growth, total seed yield, number of seeds, fresh weight, and dry weight of seeds are reduced in the presence of salinity. Only at high salinity, protein content increases in these seeds, while total carbohydrate content decreases (Koyro and Eisa, 2007).

While most quinoa is still grown in South America, it is also cultivated in the USA (Colorado and California), China, Europe, Canada, and India. It is also cultivated experimentally in Finland and the UK. Increasing amounts are being exported to the developed world like Europe and the USA. It is currently produced in Bolivia, Peru, and Ecuador; in Chile almost all quinoa seed (QS) is exported to Europe and the USA. In Europe quinoa was introduced in England in the 1970s, and later research projects focused on its production for humans and/or as a fodder crop under temperate conditions (Jacobsen and Stølen, 1993; Jacobsen *et al.*, 1994). Quinoa production has increased in the last 20 years, especially in Bolivia. The main producing countries are Bolivia, Peru, and Ecuador, which in 2007 produced 61,490 tons, up from 19,000 tons in 1973 (FAOSTAT, 2008). During 2007 quinoa production was 34,000 tons in Peru, 26,800 tons in Bolivia, and 690 tons in Ecuador (FAOSTAT, 2008).

Quinoa is a very interesting food due to its complete nutritional characteristics. It is a starchy dicotyledonous seed, and therefore not a cereal, so it is known as a pseudocereal (Ahamed *et al.*, 1998; Ando *et al.*, 2002; Chauhan *et al.*, 1992a,b; Lindeboom, 2005; Oshodi *et al.*, 1999; Ranhotra *et al.*, 1993; USDA, 2005; Wright *et al.*, 2002). This seed has been attracting attention because of the quality and nutritional value of its proteins (Ranhotra *et al.*, 1993). It is rich in the essential amino acid lysine, making it a more complete protein than many vegetables. It does not contain gluten, so it can be eaten by people who have celiac disease as well as by those who are allergic to wheat. The oil fraction of the seeds is of high quality and highly nutritious. It is also rich in iron and magnesium and provides fiber, vitamin E, copper and phosphorus, as well as some B vitamins, potassium, and zinc. Quinoa has an outer seed layer that contains saponins, which are toxic and bitter tasting, making necessary its elimination before eating or processing for the manufacture of food products. The plant's saponin content is a protective feature.

The seeds are small and have been used as flour, toasted, added to soups, or made into bread. Nowadays new food products featuring ancient grains are appearing in the market worldwide, giving new possibilities for grains like quinoa. With the emerging quinoa market the consumer trend towards ancient grains is expected to keep increasing, with international support from both political and industry organizations in Europe (Tellers, 2008). The first few quinoa products are beginning to appear in the European market. In 2003, the UK-based Anglesey introduced a chilled quinoa meat substitute called Quinova. With increasing interest in grain diversification, the food industry in 2008 can show a change in its tactics leading to new ways of revenue potential from these ancient grains (Launois, 2008; Tellers, 2008).

This review presents a summary of the available literature on the composition, chemistry, functional, and nutritional properties of quinoa seed. The focus is on macrocomponents, which are mainly responsible for the functional properties.

II. CHEMICAL, NUTRITIONAL, AND PHYSICAL PROPERTIES

QS are a complete food with high-nutritional value due mainly to their high content of good quality protein (Abugoch *et al.*, 2008; Gross *et al.*, 1989; Mahoney *et al.*, 1975; Oshodi *et al.*, 1999; Ranhotra *et al.*, 1993). Besides their protein content, many studies have been made of their lipids (Koziol, 1993; Ruales and Nair, 1993), starch (Atwell *et al.*, 1983; Coulter and Lorenz, 1990), minerals (Oshodi *et al.*, 1999), and saponin (Chauhan *et al.*, 1992a,b; Mastebroek *et al.*, 2000). QS contain minerals and vitamins like vitamin B (Koziol, 1993), vitamin C (Koziol, 1993; Lintschinger *et al.*, 1997), and vitamin E (Coulter and Lorenz, 1990; Ng and Anderson, 2005; Repo-Carrasco *et al.*, 2003; Ruales and Nair, 1993).

There is an extensive literature on QS covering different aspects, including the composition of reserves (Ando *et al.*, 2002), and chemical characterization of proteins (Abugoch *et al.*, 2008; Brinegar and Goundan, 1993; Brinegar *et al.*, 1996), fatty acid composition of the oils (Ando *et al.*, 2002; Wood *et al.*, 1993) mineral content (Ando *et al.*, 2002; Koziol, 1993); and functional and nutritional values (Abugoch *et al.*, 2008; Ogungbenle, 2003; Ogungbenle *et al.*, 2009; Ranhotra *et al.*, 1993; Ruales and Nair, 1993). However, it is necessary to consider its saponins, which are present in the pericarp of the seeds and must be removed before their use and consumption.

Biopolymers are found in specific parts of the grain (Fig. 1.1) (Prego *et al.*, 1998). For instance, starch grains (Fig. 1.2) occupy the cells of the perisperm, while lipid bodies, protein bodies with globoid crystals of phytin, and proplastids with deposits of phytoferritin are the storage components of the endosperm and embryo tissues (Ando *et al.*, 2002;

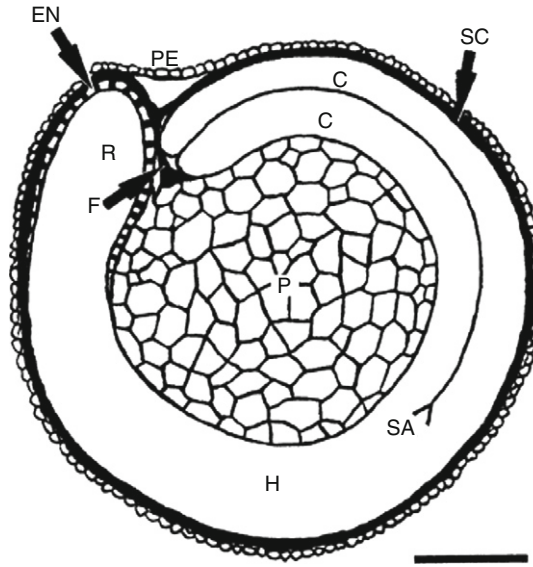

FIGURE 1.1 Medial longitudinal section of quinoa seed showing the pericarp (PE), seed coat (SC), hypocotyl-radical axis (H), cotelydons (C), endosperm (EN) (in the micropylar region only), radicle (R), funicle (F), shoot appendix (SA) and perisperm (P). Bar = 500 μm. (Prego *et al.*, 1998. Reproduced with author's permission).

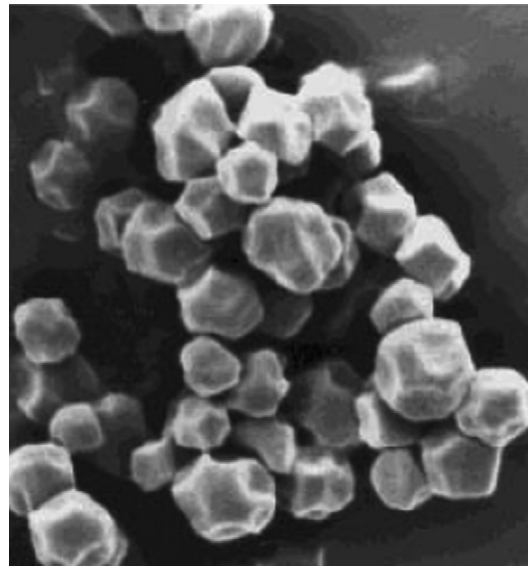

FIGURE 1.2 Scanning electron micrographs (10,000 × magnification) of quinoa starch (Qian and Kuhn, 1999; Copyright Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission).

Prego *et al.*, 1998). The embryo that surrounds the perisperm is dicotyledonous and is part of the bran fraction of the seed; it is high in proteins and lipids, and contains most of the ash, fiber, and saponins (Mastebroek *et al.*, 2000; Varriano-Marston and DeFrancisco, 1984). The shape of QS is similar to a flattened sphere; their mean equivalent diameter varies from 1.4 to 1.6 mm (Chauhan *et al.*, 1992a,b; Vilche *et al.*, 2003). As mentioned previously, carbohydrates, proteins, and lipids are the main component of the seeds, and they are mostly responsible for the functional properties that have made them new ingredients in the development of new products.

QS can be very important for improving food supplies (Repo-Carrasco *et al.*, 2003; Tellers, 2008) and as alternative food sources in other regions such as the USA and Europe (Castillo, 1995; Tellers, 2008).

III. PROTEINS

A. Chemical and nutritional aspects

The mean protein content reported in the literature for QS is 12–23% (Abugoch *et al.*, 2008; Ando *et al.*, 2002; Gonzalez *et al.*, 1989; Karyotis *et al.*, 2003; Koziol, 1992; Ruales and Nair, 1994a,b). Compared to cereal grains, the total protein content of QS (16.3% dry basis (db)) is higher than that of barley (11% db), rice (7.5% db), or corn (13.4% db), and is comparable to that of wheat (15.4% db) (Abugoch *et al.*, 2008; USDA, 2005). QS contain relatively minor proteins compared to legume seeds (Table 1.1). The amino acid composition of QS has been studied (Ranhotra *et al.*, 1993; Repo-Carrasco *et al.*, 2003; Ruales and Nair, 1993; Wright *et al.*, 2002). Relative to cereal grains, quinoa proteins (QPs) are particularly high in lysine, the limiting amino acid in most cereal grains (Table 1.1). Their essential amino acid balance is excellent because of a wider amino acid range than in cereals and legumes (Ruales and Nair, 1993), with higher lysine (5.1–6.4%) and methionine (0.4–1%) contents (Bhargava *et al.*, 2003; National Academy of Sciences, 1975; Prakash and Pal, 1998). QPs have higher histidine content than barley, soy, or wheat proteins, while the methionine + cystine content of quinoa is adequate for children (2–12 years old) and adults (Table 1.2), it is similar to that of barley and soy, and lower than the amounts in wheat. According to the FAO/WHO suggested requirements (Table 1.2) for a 10-year-old children, QPs have adequate levels of aromatic amino acids (phenylalanine and tyrosine) and similarly in histidine, isoleucine, threonine, phenylalanine, tyrosine, and valine contents. By comparison (Table 1.2), lysine and leucine in QPs are limiting amino acids for 2–5-year-old infants or children, while all the essential amino acids of this protein are sufficient according to FAO/WHO

TABLE 1.1 Amino acids composition of quinoa seed, barley, soybeans, and wheat[a]

Amino acid	Quinoa seed	Barley pearled	Soybean raw	Wheat durum
	mg/g protein			
Arginine	77.3	50.1	69.5	83.4
Aspartic acid	80.3	62.5	136.3	94
Cystine	14.4	22.1	12.1	20.5
Glycine	49.2	36.2	38.6	45.5
Glutamic acid	132.1	261.2	151	195.1
Histidine	28.8	22.5	26.7	23.5
Isoleucine	35.7	36.5	44.5	43.2
Leucine	59.5	98.2	72	82.8
Lysine	*54.2*	*37.2*	*57.8*	*36.2*
Methyonine	21.8	19.2	10.6	23.5
Phenylalanine	42	56.1	49.2	53.5
Serine	40.2	42.2	50	52.6
Threonine	29.8	34	38.6	35.8
Tryphtophan	11.8	16.6	12.2	11.5
Tyrosine	18.9	28.7	36.2	33.4
Valine	42.1	49	47.6	61.1
Alanine	41.6	39	42.2	58

[a] USDA (2005).

suggested requirements for 10–12-year-old children. The two quinoa isolates studied in this work showed a good amino acid profile and could be a good source of proteins for feeding infants and children.

The nutritional value of a food is determined by its protein quality, which depends mainly on its amino acid content, digestibility, influence of antinutritional factors, and the tryptophan to a large neutral amino acids ratio (Comai *et al.*, 2007).

Mahoney *et al.* (1975) reported the protein efficiency ratio (PER) values for QP, and the protein quality of cooked quinoa was like that of casein. According to these authors, the PER of the cooked quinoa was 30% greater than that of uncooked quinoa. Recently, Ranhotra *et al.* (1993) also concluded that the quality of protein in quinoa equals that of casein. Gross *et al.* (1989) reported a high apparent digestibility and a high PER of washed QS; they found that the PER is almost equal to that of casein. Digestibility of the proteins in raw washed quinoa was described by Ruales and Nair (1993), who found 83% (casein, 91%). Both reports (Gross *et al.*, 1989; Ruales and Nair, 1993) showed that it is necessary to remove the saponins to increase digestibility.

TABLE 1.2 Comparison of essential amino acids content of barley, corn and wheat to FAO/WHO suggested requirement

	Quinoa seed[a]	Barley pearled[a]	Soybeans raw[a]	Wheat durum[a]	FAO/WHO suggested requirements[b]		
Amino acids	mg/g protein				2–5-yearold	10–12-yearold	Adult
Histidine	28.8	22.5	27.6	23.5	19	19	16
Isoleucine	35.7	36.5	44.5	38.9	28	28	13
Leucine	59.5	98.2	72	68.1	66	44	19
Lysine	*54.2*	*37.2*	*57.8*	*22.1*	58	44	16
Methyonine and Cystine	36.2	41.3	28.9	22.7	25	22	17
Phenylalanine and Tyrosine	60.9	84.7	84.8	85.9	63	22	19
Threonine	29.8	34	38.6	26.7	34	28	9
Tryphtophfan	11.4	16.6	12	12.8	11	9	5
Valine	42.1	49	57.1	41.6	35	25	13

[a] USDA (2005).
[b] Friedman and Brandon (2001).

Protein digestibility can increase with adequate heat treatment (Ruales and Nair, 1993). Lopez de Romana *et al.* (1981) found that digestibility of QS is the limiting factor in protein and energy utilization, and that milling improves significantly the digestibility of fat and carbohydrates. Lorenz and Coulter (1991) obtained corn grits with different levels of quinoa and found that quinoa addition produced extruded products which were higher in protein than corn grit products, but had a somewhat lower *in vitro* digestibility.

The importance of the nonprotein tryptophan fraction is due to the fact that it is the only one that can enter the brain and is more easily absorbed, so it guarantees a greater amount available for uptake by the central nervous system. So the tryptophan content of QPs is similar to that of wheat, but higher than that of other cereals (Comai *et al.*, 2007). Free tryptophan in quinoa flour has values similar to those of wheat and oat; lower than those of barley and pearl millet, but higher than that in rice, maize, and rye (Comai *et al.*, 2007).

B. Active biopeptides

Aluko and Monu (2003) obtained active biopeptides by enzymatic hydrolysis, and they suggest that short-chain peptides are more active than long-chain peptides. Low-molecular-weight peptides possess higher potential than high-molecular-weight peptides as antihypertensive agents or as compounds that reduce the amount of free radicals.

C. Structural aspects

QS, like those of other plants, store proteins in the embryo to provide nutrients for growth and development (Herman and Larkins, 1999). In the food area, proteins stored in seeds are the source of the proteins consumed directly as food by humans (Shewry *et al.*, 1995). Stored proteins provide building blocks for rapid growth upon seed and pollen germination (Herman and Larkins, 1999). Osborne (1924) introduced a classification of plant proteins based on their solubility in a series of solvents, such as albumins in water, and globulins in saline.

Albumins and globulins represent the main storage proteins in QS (Brinegar and Goundan, 1993; Brinegar *et al.*, 1996). QS proteins have been characterized electrophoretically by different authors (Abugoch *et al.*, 2008; Brinegar and Goundan, 1993; Brinegar *et al.*, 1996; Fairbanks *et al.*, 1989). Fairbanks *et al.* (1989) showed that QS polypeptides can be classified as albumin or globulin. Insignificant amounts of protein were present in the prolamin fraction, and all the polypeptides in the glutelin fraction had electrophoretic mobilities identical to those of albumins and globulins (Fairbanks *et al.*, 1989).

Brinegar and Goundan (1993) specifically characterized individual seed storage proteins by isolating and characterizing the 11S seed storage protein, which they call chenopodin. The 11S globulin is a hexameric protein consisting of six pairs of acidic and basic subunits, with each subunit pair connected by a disulfide bond; the sequence similarities of six binding regions suggest that the quinoa 11S hexamer has a structure similar to glycinin (Barrett, 2006). *Chenopodin*, one of the major storage protein fractions (37% of total protein), is an oligomeric protein with a quaternary structure that was purified by gel filtration (320 kDa) (Brinegar and Goundan, 1993). Quinoa globulin is made of monomers or subunits each of which consists of a basic and an acidic polypeptide, with molecular mass of 20–25 and 30–40 kDa, respectively, linked by disulfide bonds (Abugoch *et al.*, 2008; Brinegar and Goundan, 1993). Brinegar and Goundan (1993) determined the amino acid composition of the A and B polypeptides, and compared it with the composition of the native chenopodin. Chenopodin has a high content of glutamine—glutamic acid, asparagines—aspartic acid, arginine, serine, leucine, and glycine. According to the FAO reference protein (FAO, 1973), chenopodin meets the requirements for leucine, isoleucine, and phenylalanine + tyrosine.

The other major protein (35% of total protein) is a 2S-type protein also known as albumin according to Osborne (1924); with a molecular mass of 8–9 kDa. Brinegar *et al.* (1996) reported for the purified quinoa 2S protein fraction an electrophoretically heterogeneous collection of polypeptides having molecular mass of 8–9 kDa under reducing conditions. The amino acid composition of this protein showed that it is high in cysteine, arginine, and histidine (Brinegar *et al.*, 1996).

IV. CARBOHYDRATES

A. Composition, physical, chemical, and structural properties

Carbohydrates can be classified according to their degree of polymerization into three principal groups: sugars (monosaccharides, disaccharides, polyols), oligosaccharides, and polysaccharides (starch and nonstarch) (FAO, 1998). Table 1.3 presents the carbohydrate composition of QS, barley, and rice. The carbohydrate (by difference, db) content of QS is comparable to that of barley and rice. Starch is the major component of quinoa carbohydrates, and it is present between 32% and 69.2% (Ahamed *et al.*, 1998; Ando *et al.*, 2002; Chauhan *et al.*, 1992a,b; Lindeboom, 2005; Oshodi *et al.*, 1999; Ranhotra *et al.*, 1993; USDA, 2005; Wright *et al.*, 2002). Besides, total dietary fiber of quinoa is near that of cereals (7–9.7% db), and the soluble fiber content is reported between 1.3% and 6.1% (db)

TABLE 1.3 Carbohydrate composition of quinoa seed, rice, and barley (% dry basis)

	Quinoa	Rice[a]	Barley[a]
Carbohydrate by difference	73.6[a]–74[b]	79.2	77.7
Starch	52.2[a]–69.2[c]		
Fiber total dietary	7[a]–9.7[d]	2.8	15.6
Insoluble fiber	6.8[c]–8.4[d]		
Soluble fiber	6.1[c]–1.3[d]		
Sugar	2.9[d]		0.8

[a] Data from USDA (2005).
[b] Data from Wright *et al.* (2002).
[c] Data from Mundigler (1998).
[d] Data from Ranhotra *et al.* (1993).

(Table 1.3). Finally, there is about 3% of simple sugars (Ranhotra *et al.*, 1993). The individual sugars present in quinoa are mostly maltose, followed by D-galactose and D-ribose, and it also contains fructose and glucose (Oshodi *et al.*, 1999).

Carbohydrates play a basic nutritional function and they may have different physiological health effects, such as: provision of energy, effects on satiety/gastric emptying, control of blood glucose and insulin metabolism; protein glycosylation; cholesterol and triglyceride metabolism (FAO, 1998). Carbohydrates from quinoa can be considered a nutraceutical food because they have beneficial hypoglycemic effects and induce lowering of free fatty acids. Studies made in individuals with celiac disease showed that the glycemic index of quinoa was slightly lower than that of gluten-free pasta and bread (Berti *et al.*, 2004). Besides, quinoa induced lower free fatty acid levels than gluten-free pasta and significantly lower triglyceride concentrations compared to gluten-free bread (Berti *et al.*, 2004). Some nutraceutical effects of quinoa have been reported, but that requires further study (Berti *et al.*, 2004).

In vitro digestibility (α-amylase) of raw quinoa starch was reported at 22%, while that of autoclaved, cooked, and drum-dried samples was 32%, 45%, and 73%, respectively (Ruales and Nair, 1994a). Saponins did not affect the digestibility of the starch. The total dietary fiber content in quinoa flour is affected by thermal treatment, while the insoluble dietary fiber fraction does not change with heat treatment (Ruales and Nair, 1994b).

1. Structure of quinoa starch

Starch is second only to cellulose in natural abundance, and it is the major energy reserve in plants. The most important sources of starch are cereal grains, legumes, and tubers. The glucose polymers that make up starch come in two molecular forms, linear and branched. The former is referred

TABLE 1.4 Starch composition of quinoa, rice, barley (% dry basis)

	Quinoa[a,b,c,d]	Rice[e]	Barley[f]
Amylose	3.5–22.5	7.4–29.8	1–45
Amylopectin	77.5	61	

[a] Tang *et al.* (2002).
[b] Qian and Kuhn (1999).
[c] Tari *et al.* (2003).
[d] Lindeboom (2005).
[e] Tukomane and Varavinit (2008).
[f] Morrison *et al.* (1986).

to as amylose and the latter as amylopectin. In nature, α-D-glucose is used to form the starch polymers (Murphy, 2000). Quinoa starch consists of two polysaccharides: amylose and amylopectin. In native starches, the amylose content is 20–30% and the amylopectin content is 70–80%. The *amylose* content (Table 1.4) of quinoa starch varies between 3% and 20% (Inouchi *et al.*, 1999; Lindeboom, 2005; Praznik *et al.*, 1999; Qian and Kuhn, 1999; Tang *et al.*, 2002; Watanabe *et al.*, 2007). The amylose fraction of quinoa starch is low, similar to that of some rice varieties, and higher than that of some barley varieties (Morrison *et al.*, 1986) (Table 1.4).

Quinoa starch has an average molar mass of 11.3×10^6 g/mol, a value lower than that of waxy corn starch (17.4×10^6 g/mol) or rice starch ($0.52–1.96 \times 10^8$ g/mol) (Park *et al.*, 2007; Praznik *et al.*, 1999), and higher than that of wheat starch (5.5×10^6 g/mol) (Praznik *et al.*, 1999). Quinoa starch is highly branched, with a minimum degree of polymerization of 4600 glucan units, a maximum of 161,000, and a weighted average of 70,000 (Praznik *et al.*, 1999). Chain length can depend on the botanical origin of the starch, but it will be of the order of 500–6000 glucose units. According to Tang *et al.* (2002) the number-average degree of polymerization of quinoa amylose (900) is lower than that of barley (1,700). Amylose has an average of 11.6 chains per molecule.

Amylopectin is one of the largest molecules in nature. Very few results on the molecular weight of cereal amylopectin have been reported because cereal starches are difficult to dissolve in water and may be easily degraded. In the literature, amylose is determined directly, but amylopectin only by difference. In quinoa starch the *amylopectin* content according to Tari *et al.* (2003) is 77.5%. The amylopectin fraction is high and comparable to that of some varieties of rice (Tukomane and Varavinit, 2008) (Table 1.4). Quinoa amylopectin has a unique chain length distribution as a waxy amylopectin, with 6700 glucan units for the amylopectin fraction of quinoa starch (Tang *et al.*, 2002).

Quinoa amylopectin, like that of amaranth and buckwheat, contains a large number of short chains from 8 to 12 units and a small number of longer chains of 13–20, compared to the endosperm starches of other

TABLE 1.5 Granule size of starches from quinoa, amaranth, rice, barley (μm)

Quinoa	Amaranth	Rice	Barley
0.6[a]–2[b,c]	1–2[c]	3–8[d]	2–3 and 12–32[e]

[a] Ruales and Nair (1993).
[b] Tang *et al.* (2002).
[c] Qian and Kuhn (1999).
[d] Clédat *et al.* (2004).
[e] Lindeboom *et al.* (2004).

cereals (Inouchi *et al.*, 1999). Quinoa glucans were classified by Praznik *et al.* (1999) as amylopectin-type short-chain branched glucan.

Granule size affects the physicochemical characteristics of starch. Granule size and shape are related to the biological source from which the starch is isolated. In general, granule size may vary from less than 1 μm to more than 100 μm according to Lindeboom *et al.*, 2004, who defined the following classes according to size: large (>25 μm), medium (10–25 μm), small (5–10 μm), and very small (<5 μm) granules. Quinoa starch has a very small granule size and has been reported to be 1–2 μm (Ando *et al.*, 2002; Atwell *et al.*, 1983; Chauhan *et al.*, 1992a,b; Lindeboom, 2005; Lorenz, 2006; Qian and Kuhn, 1999; Tang *et al.*, 2002; Tari *et al.*, 2003). Table 1.5 shows granule sizes from different origins, showing that quinoa starch is comparable to that of amaranth and smaller than that of rice or barley. Quinoa starch has small granules and can be used to produce a creamy, smooth texture that exhibits properties similar to fats, or it can be incorporated into biofilms (Lindeboom *et al.*, 2004).

Figure 1.2 shows the polygonal shape of quinoa starch by scanning electron microscopy (SEM) (Lindeboom, 2005; Qian and Kuhn, 1999; Wang *et al.*, 2003), similar to that of amaranth and rice starch (Kong *et al.*, 2009; Qian and Kuhn, 1999). According to Ruales and Nair (1994a) the starch in QS also has polygonal granules, and they found that particles can be present singly and as spherical aggregates. The 20–30-μm diameter starch granule aggregates are packed in the quinoa perisperm (Ando *et al.*, 2002).

X-ray diffraction studies have been used to explain the structure of whole starch and amylose. Starch granules, depending on their botanical origin, amylose/amylopectin ratio, and amylopectin branch length, show three types of X-ray diffraction patterns, associated with different crystalline polymorphic forms: A-type (cereal), B-type (tubers), and C-type (A and B crystals coexisting in the granule) (Lopez-Rubio *et al.*, 2008; Qian and Kuhn, 1999). Quinoa starch presents the typical A X-ray diffraction pattern reflections at 15.3°, 17°, 18°, 20°, and 23.4° 2θ angles; characteristic of cereal starches (Lopez-Rubio *et al.*, 2004; Qian and Kuhn, 1999; Watanabe *et al.*, 2007). The degree of relative crystallinity is between 35% and 43% (Qian and Kuhn, 1999; Tang *et al.*, 2002; Watanabe *et al.*, 2007).

The relative crystallinity of quinoa starch has been described as higher than that of normal barley starch, lower than that of amaranth starch, and similar to that of waxy barley starch (Qian and Kuhn, 1999; Tang *et al.*, 2002).

For each kind of starch granule it is possible to find a characteristic thermogram by differential scanning calorimetry (DSC). Thermograms of quinoa starch show two thermal transitions; one for gelatinization of the starch and another for the amylose–lipid complex (Ruales and Nair, 1994b; Tang *et al.*, 2002). The gelatinization properties of starch are related to a variety of factors including the size, proportion and kind of crystalline organization, and the ultrastructure of the starch granule. Quinoa starch gelatinizes at a relatively low temperature (T_0 = 46.1–57.4 °C, T_p = 54.2–61.9 °C, T_c = 66.2–68.5 °C) (Inouchi *et al.*, 1999). The first thermal transition gives the gelatinization temperature, and it has been reported between 62.6 and 67 °C (Qian and Kuhn, 1999; Ruales and Nair, 1994b; Tang *et al.*, 2002). For this transition the enthalpy reported for quinoa starch is between 1.66 and 12.2 J/g (Qian and Kuhn, 1999; Tang *et al.*, 2002). Comparative thermal properties are presented in Table 1.6. It shows that quinoa starch has a similar gelatinization temperature than amaranth starch and higher than rice starch. According to Lindeboom (2005), the gelatinization onset and peak temperatures of quinoa starches ranged from 44.6 to 53.7 °C and from 50.5 to 61.7 °C, respectively, and the gelatinization enthalpies from 12.8 to 15 J/g of dry starch. The gelatinization temperatures are positively dependent of amylose content (Lindeboom, 2005; Youa and Izydorczyk, 2007). The quinoa starches exhibited lower gelatinization temperatures than waxy barley and amaranth starches (Qian and Kuhn, 1999; Youa and Izydorczyk, 2007).

The pasting properties of quinoa starch are reported by Qian and Kuhn (1999) and show a pasting temperature of 66.8 °C, comparable to quinoa starch pasting values (63–64 °C) reported by Lindeboom (2005).

TABLE 1.6 Thermal properties of some starches

	Quinoa[a,b]	Waxy barley[c]	Amaranth[a]
Gelatinization enthalphy ΔH (J/g)	1.66–15	14.8	2.58
T_0 °C	44.6–59.9	66.4	66.3
T_p °C	54.5–69.3		74.5
T_c °C	71–86.4		86.9

[a] Qian and Kuhn (1999).
[b] Lindeboom (2005).
[c] Youa and Izydorczyk (2007).
T_0: Gelatinization onset temperature (°C). T_p: Gelatinization peak temperature (°C). T_c: Gelatinization conclusion temperature (°C).

Rapid Visco Analysis (RVA) shows the normal pasting feature of cereal and root starches (Qian and Kuhn, 1999). Finally, quinoa starch has excellent stability under freezing and retrogradation processes (Ahamed *et al.*, 1998). Quinoa starch can be affected by heat treatment, showing changes in the degree and extent of degradation (Ruales and Nair, 1994b).

V. LIPIDS AND LIPIDIC COMPOUND

A. Composition, nutritional properties

QS have been considered an alternative oilseed crop due to their lipidic fraction (Koziol, 1993). Besides the high content and good biological quality of their proteins, QS have an interesting lipid composition of about 1.8–9.5% (Koziol, 1993; Masson and Mella, 1985; Oshodi *et al.*, 1999; Ranhotra *et al.*, 1993; Ryan *et al.*, 2007; USDA, 2005; Wood *et al.*, 1993). Quinoa has an oil content (7% dry basis) higher than corn (4.9% dry basis) and lower than soy (20.9% dry basis) (Koziol, 1993; USDA, 2005). Cytochemical and ultrastructural analyses reported by Prego *et al.* (1998) show that lipid bodies are the storage components of the cells of the endosperm and embryo tissues (Fig. 1.3).

According to Przybylski *et al.* (1994), QS lipids contain high amounts of neutral lipids in all the seed fractions analyzed. Triglycerides are the major fraction present, accounting for over 50% of the neutral lipids. Diglycerides are present in whole seeds and contribute 20% of the neutral lipid fraction. Lysophosphatidyl ethanolamine and phosphatidyl choline are the most abundant (57%) of the total polar lipids (Przybylski *et al.*, 1994). Some researchers have characterized the fatty acid composition of quinoa lipids (Table 1.7) as follows: total saturated 19–12.3%, mainly palmitic acid; total monounsaturated 25–28.7%, mainly oleic acid, and total polyunsaturated 58.3%—chiefly linoleic acid (about 90%) (Masson and Mella, 1985; Oshodi *et al.*, 1999; Ranhotra *et al.*, 1993; Ryan *et al.*, 2007; USDA, 2005; Wood *et al.*, 1993). Omega-6 and omega-3 fatty acids are essential fatty acids because they cannot be synthesized by humans, who must obtain them from foods. The essential fatty acids are metabolized to longer chain fatty acids of 20 and 22 carbon atoms. Linoleic acid is metabolized to arachidonic acid and linolenic acid to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). EPA and DHA play important roles in prostaglandin metabolism, thrombosis and atherosclerosis, immunology and inflammation, and membrane function (Simopoulos, 1991; Youdim *et al.*, 2000). The fatty acid profile of QS is similar to corn and soybean oil (Koziol, 1992; Oshodi *et al.*, 1999; Youdim *et al.*, 2000). Essential fatty acids are important acids, like linoleic and linolenic acids, that are necessary substrates in animal metabolism. Linoleic acid (C18:2)

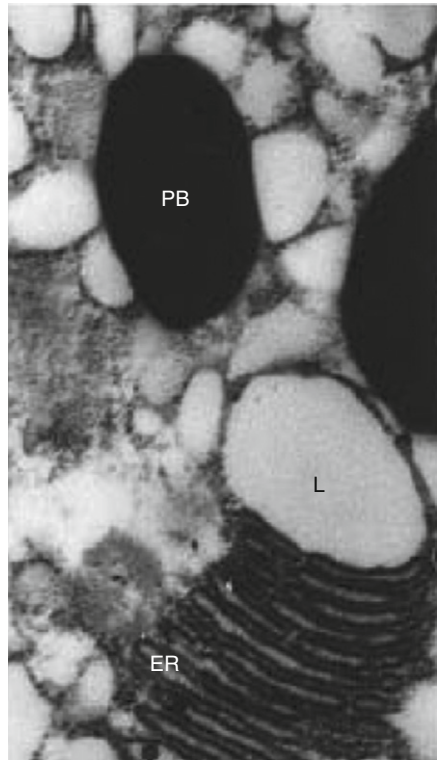

FIGURE 1.3 Transmission electron micrographs of sections of the endosperm. An enlargement section of a cell of the endosperm showing lipid bodies (L) and protein bodies (PB), next to endoplasmic reticulum (Prego *et al.*, 1998. Reproduced with author's permission).

is one of the most abundant polyunsaturated fatty acids (PUFA) identified in QS; PUFAs have several positive effects on cardiovascular disease (Abeywardena *et al.*, 1991; Keys and Parlin, 1966) and improved insulin sensitivity (Lovejoy, 1999). The oil fraction of QS has high quality and is highly nutritious, based on the fact that it has a high degree of unsaturation, with a polyunsaturation index of 3.9–4.7.

In this fraction, not only the fatty acid composition is important. Another important feature is the natural presence of a high amount of vitamin E (α-tocopherol), 0.59–2.6 mg/100 g in the seeds (Coulter and Lorenz, 1990; Ryan *et al.*, 2007; USDA, 2005), which acts as a natural defense against lipid oxidation (Ng *et al.*, 2007). This fact could lead to a very stable oil from QS, with vitamin E acting as a natural antioxidant. The (β + γ)-tocopherol content in quinoa whole flour has been reported as 3.1–5.5 mg/100 g (Ruales and Nair, 1993; Ryan *et al.*, 2007). *The chemical stability* of the lipids in quinoa flour was studied by Ng *et al.* (2007), who

TABLE 1.7 Fatty acid composition of crude fat from quinoa seed, corn, and soy oil

Fatty acid	Quinoa[a]	Soy[b]	Corn[b]
Saturated			
Myristic C14:0	0.1–2.4	Traces	Traces
Palmitic C16:0	9.2–11.1	10.7	10.7
Stearic C18:0	0.6–1.1	3.6	2.8
Monounsaturated			
Myristoleic C14:1	1	–	–
Palmitoleic C16:1	0.2–1.2	0.2	trazas
Oleic C18:1	22.8–29.5	22	26.1
Polyunsaturated (PUFA)			
Linoleic C18:2 ($n - 6$)	48.1–52.3	56	57.7
Linolenic C18:3 ($n - 3$)	4.6–8	7	2.2

[a] Masson and Mella (1985).
[b] USDA (2005).

found that the lipids were stable during 30 days, and this stability is due to vitamin E present naturally.

Squalene and phytosterols are components present in the unsaponifiable lipid fraction of foods (as tocopherols). Squalene is an intermediary in cholesterol biosynthesis, and 33.9–58.4 mg/100 g of it was found in the lipid fraction of quinoa (Jahaniaval *et al.*, 2000; Ryan *et al.*, 2007); squalene is the biochemical precursor of the whole family of steroids, and besides their effective antioxidant activity, tocotrienols have other important functions, in particular in maintaining a healthy cardiovascular system and a possible role in protection against cancer (Nesaretnam, 2008). Squalene is used as a bactericide and as an intermediate in many pharmaceuticals, organic coloring materials, rubber chemicals, and surface-active agents (Ahamed *et al.*, 1998).

Phytosterols are natural components of plant cell membranes that are abundant in vegetable oils, seeds, and grains. Phytosterols have different biological effects such as antiinflammatory, antioxidative, and anticarcinogenic activity, and cholesterol-lowering capacity (Moreau *et al.*, 2002). The levels of phytosterols from QS reported by Ryan *et al.* (2007) were β-sitosterol 63.7 mg/100 g, campesterol 15.6 mg/100 g, and stigmasterols 3.2 mg/100 g, which are the most abundant plant sterols. These levels are higher than in pumpkin seeds, barley, and maize, but lower than in lentils, chick peas, or sesame seeds (Ryan *et al.*, 2007). The recommended doses of free phytosterols are 0.8–1.0 g of equivalents per day, including natural sources, and they are important dietary components for lowering low density lipoprotein (LDL) cholesterol and maintaining good heart health (Berger *et al.*, 2004).

VI. ANTIOXIDANT CAPACITY, PHENOLIC COMPOUNDS, AND FLAVONOIDS

Zhu *et al.* (2001) have isolated six flavonol glycosides from QS; these compounds exhibited antioxidant capacity, suggesting that QSs can serve as a good source of free radical scavenging agents. Gorinstein *et al.* (2008) reported a 0.051% db tannin content for quinoa, a value comparable to that of amaranth. The reported contents (db) were 251.5 μg/g of ferulic acid, 0.8 μg/g of *p*-coumaric acid, and 6.31 μg/g of caffeic acid (Gorinstein *et al.*, 2008). These authors found antioxidant values expressed as total radical-trapping antioxidative potential (TRAP), ferric ion-reducing antioxidant power (FRAP), cupric-reducing antioxidant capacity (CUPRAC), and nitric oxide (NO). The TRAP value for quinoa was 251 nM mL^{-1} in acetone extract and 1.686 nM mL^{-1} in water extract, the FRAP value was 2.3 μM trolox equivalent g^{-1}, a CUPRAC value of 5 μM trolox equivalent g^{-1}; and 32% of NO. Gorinstein *et al.* (2008) showed that quinoa has higher antioxidant activity than some cereals (rice and buckwheat).

VII. SAPONINS

Saponins are a wide group of glycosides found in plants; their name comes from the plant genus *Saponaria*, whose root was used as soap (sapo, onis = soap) (Sparg *et al.*, 2004); so they are water soluble and form foaming solutions. Saponins are steroid or triterpenoid glycosides, with the latter found more commonly in crops (Francis *et al.*, 2002). These compounds have a bitter taste and are considered toxic in large amounts. They are present in the whole quinoa plant; where their natural function is to defend the plant from the external medium. In general, QSs contain saponins in the seed coat (except sweet varieties, without saponin or containing less than 0.11%). Saponins are the main antinutritional factor present in the seed cover (Ruales and Nair, 1994a,b); studies in rats revealed that animals fed with unwashed quinoa diets showed growth damage and reduced food conversion efficiency (Gee *et al.*, 1996). According to their chemical structure, saponins can be partially removed by washing with water (Chauhan *et al.*, 1999), but even after washing some saponin remains in the seed. Zhu *et al.* (2002) recommended the use of slightly alkaline water rather than neutral water to debitter QSs. Brady *et al.* (2007) have reported that the bitter taste imparted by saponins could potentially be reduced by extrusion and roasting processes.

Saponins are compounds that contain sugar chains and a triterpenoid aglycone (sapogenin) in their structure (Sparg *et al.*, 2004). They are categorized according to the number of sugar chains in their structure as

mono-, di-, or tridesmosidic. Four main structures of sapogenins have been identified in quinoa: doleanolic acid, hederagenin, phytolaccagenic acid, and 30-*o*-methylspergulagenat (Zhu *et al.*, 2002). The major carbohydrates are glucose, arabinose and galactose. Besides, 20 triterpene saponins have been isolated from different parts of *Chenopodium quinoa* (flowers, fruits, seed coats, and seeds) (Kuljanabhagavad *et al.*, 2008; Zhu *et al.*, 2002).

The sapogenin content in seeds of sweet genotypes varied from 0.02% to 0.04% and in seeds of bitter genotypes from 0.14% to 2.3% (Mastebroek *et al.*, 2000; Güçlü-Üstündağ and Mazza, 2007). These values are higher than those in soybean and oat, but lower than in green pea and yucca (Güçlü-Üstündağ and Mazza, 2007).

Saponins have been considered toxic for different organisms. Meyer *et al.* (1990) found toxicity to brine shrimp. Woldemichael and Wink (2001) found monodesmoside saponins hemolytically active. The hemolysis may be produced by the interaction of the saponins with membranes, producing pores that lead to rupture of the (Seeman *et al.*, 1973). Kuljanabhagavad *et al.* (2008) described mainly saponins with an aldehyde group as cytotoxic in HeLa (cervix adenocarcinoma) cell line.

Saponins have shown insecticidal, antibiotic, fungicidal, and pharmacologic activity. Woldemichael and Wink (2001) found five quinoa saponins (glycosides of oleanolic acid and hederagenin) that showed some *antifungal* activity on *Candida albicans*; Stuardo and San Martín (2008) found higher antifungal activity against *Botrytis cinerea* with alkali-treated quinoa saponin.

Nowadays saponins have been studied because different beneficial properties to health have been described. Saponins possess a broad variety of biological effects: analgesic, antiinflammatory, antimicrobial, antioxidant, antiviral, and cytotoxic activity, effect on the absorption of minerals and vitamins and on animal growth, hemolytic and immunostimulatory effects, increased permeability of the intestinal mucosa neuroprotective action, and reduction of fat absorption (Güçlü-Üstündağ and Mazza, 2007). However, the biological properties of quinoa saponins require further study.

Finally, saponins have commercial–industrial importance as they are used in the preparation of soaps, detergents, and shampoos.

VIII. MINERALS AND VITAMINS

QS are also rich in micronutrients such as minerals and vitamins. Table 1.8 shows the mineral content of QS and quinoa flour. The main minerals are potassium, phosphorus, and magnesium (Table 1.8). According to the National Academy of Sciences (2004) the magnesium, manganese, copper, and iron present in 100 g of QS cover the daily needs of

TABLE 1.8 Mineral composition whole quinoa seed, dehulled quinoa seed, quinoa flour, oat, barley (mg/100 g)

	Whole QS[a]	Dehulled QS[a]	Quinoa flour[b,c]	Oat[d]	Barley[d]
Calcium	86.3	55.1	70–86	58	29
Phosphorous	411	404.9	22–462	734	221
Potassium	732	656	714–855	566	280
Magnesium	502	467.9	161–232	235	79
Iron	15	14.2	2.6–6.3	5.4	2.5
Manganese	n.r.	n.r.	3.5	5.6	1.3
Copper	n.r.	n.r.	0.7–7.6	0.4	0.4
Zinc	4	4	3.2–3.8	3.11	2.1
Sodium	n.r	n.r.	2.7–93	4	9

[a] Konishi *et al.* (2004).
[b] Ranhotra *et al.* (1993).
[c] Oshodi *et al.* (1999).
[d] USDA (2005).
n.r.: not reported.

infants and adults, while the phosphorus and zinc content in 100 g is sufficient for children, but covers 40–60% of the daily needs of adults. The potassium content can contribute between 18% and 22% of infant and adult requirements, while the calcium content can contribute 10% of the requirements. However, the mineral content of QS is higher than that of cereals like oat (except phosphorus) or barley, especially that of potassium, magnesium, and calcium (Table 1.8).

In their research, Konishi *et al.* (2004) found that abrasion of QS (for saponin elimination) caused specifically a decrease in calcium content. On the other hand, they found that the distribution of minerals in QS revealed that phosphorus and magnesium were localized in embryonic tissue, while calcium and potassium were present in the pericarp (Table 1.8).

The vitamin content (Table 1.9) is also interesting, because QS have high levels of vitamin B6 and total folate, whose amounts in 100 g can cover the requirements of children and adults. The riboflavin content in 100 g contributes 80% of the daily needs of children and 40% of those of adults (National Academy of Sciences, 2004). The niacin content does not cover the daily needs, but is beneficial in the diet. Thiamin values in quinoa are lower than those in oat or barley, but those of niacin, riboflavin, vitamin B6, and total folate are higher (Ranhotra *et al.*, 1993; USDA, 2005).

IX. FUNCTIONAL PROPERTIES

The functional properties of food biopolymers are important in food product formulation and manufacture, because their technological properties are dependent on the use of biopolymers. These properties are

TABLE 1.9 Vitamin composition quinoa flour, oat, barley (mg/100 g)

	Quinoa flour[a,b]	Oat[b]	Barley[b]
Thiamin	0.29–0.36	0.763	0.191
Riboflavin	0.30–0.32	0.139	0.114
Niacin	1.24–1.52	0.961	4.604
B6	0.487[b]	0.119	0.260
Folate total	0.184[b]	0.056	0.023

[a] Ranhotra *et al.* (1993).
[b] USDA (2005).

related to interaction with water, such as water-holding capacity (WHC), water imbibing capacity (WIC), solubility, viscosity. Another group of functional properties are related to polymer interaction such as gelation, and finally interfacial properties like foaming and emulsifying. The natural polymers like protein or starch have diverse and heterogeneous structures that condition their use in the food industry. The functional properties of food macromolecules are dependent on many factors such as exposure groups, hydrophobic area, water activity, ionic force, pH, temperature, size, charge density, hydrophilic/hydrophobic ratio, and changes in the environment.

Some functional properties of quinoa flour and of each component of QS are described below and are shown synoptically in Table 1.10.

A. Functional properties of quinoa flour

Some functional properties of quinoa flour have been described, mainly solubility, WHC, gelation, and foaming and emulsifying capacity.

Solubility is related to the hydrophilic–hydrophobic balance of the proteins and the thermodynamics of its interaction with the solvent. Protein solubility is pH dependent. Ruales *et al.* (1993) and Oshodi *et al.* (1999) described the functional properties of quinoa flour. Ruales *et al.* (1993) studied the protein *solubility* of quinoa flour in relation to heat (cooking and autoclaving) and found that solubility is higher in cooked samples with solubility values of 5.4–15.6%. Ogungbenle (2003) and Oshodi *et al.* (1999) studied solubility related to pH and found solubility values of about 15–52%, corresponding to minimum solubility at pH 6 and maximum at pH 10. The solubility values of quinoa flour in the acid pH region imply that the protein may be useful in the formulation of beverages, dehydrated soups and sauces, and low-acid foods.

Another property related to hydration is the WHC, which is expressed as weight increase. Ogungbenle (2003) and Ogungbenle *et al.* (2009) reported the same value of 147%. The WHC decreased from 147% to

TABLE 1.10 Functional properties of quinoa

Flour	Solubility[a,b,c], water holding capacity[b,c,d], oil holding capacity, emulsifying and foaming capacity[b,c,d], gelation[b,c,d]
Protein concentrate and protein isolate	Solubility[e,f], water-holding capacity[e,f], water imbibing capacity[f], emulsifying and foaming capacity[e]
Starch	Water absorption power[g], solubility[h,i], viscosity[h,i], freeze–thaw stability[h,i], water binding capacity[i], Brabender viscograph[j]

[a] Ruales *et al.* (1993).
[b] Oshodi *et al.* (1999).
[c] Ogungbenle (2003).
[d] Ogungbenle *et al.* (2009).
[e] Aluko and Monu (2003).
[f] Abugoch *et al.* (2008).
[g] Tang *et al.* (2002).
[h] Ahamed *et al.* (1996).
[i] Lindeboom (2005).
[j] Praznik *et al.* (1999).

79.5% in the presence of salts (salt concentration between 0.5% and 10%) (Ogungbenle *et al.*, 2009). The *gelation* property was determined by the lowest flour concentration required for gelation (Alobo, 2003). According to Ogungbenle (2003) and Oshodi *et al.* (1999), the lowest gelation concentration of quinoa was 16% (w/v) in distilled water. The addition of salts decreased the lowest gelation concentration of 10–14% (Ogungbenle *et al.*, 2009). Quinoa flour may not be a good gel forming agent. However, it was observed that addition of different salts at low concentration (0.5%) improved the gel forming property of quinoa, and this effect was better with KCl (Ogungbenle *et al.*, 2009). The other functional properties measured in quinoa flour are those related to surface tension, like *foaming and emulsifying capacity*. The foaming capacity and stability of the flour were low, with volume increase values between 9% and 4% stability (Ogungbenle, 2003). The effect of salts on the foaming capacity was studied by Ogungbenle *et al.* (2009), who found an increase in foaming capacity and stability with salt addition, especially of Na_2SO_4, KCl, NaCl, and CH_3COONa at high concentrations (10%). Quinoa has a low-foaming capacity and stability, and salt addition may improve this property, but high concentrations around 10% are not useful for human consumption. In this relation, further studies are needed on enzymatic crosslinking of QPs using transglutaminase.

Emulsifying capacity and stability were measured by Ogungbenle (2003), Oshodi *et al.* (1999), and Ogungbenle *et al.* (2009); they found an emulsifying capacity of 104% with a stability of 45% (according to the methods

described by Alobo, 2003), and also a salt dependence. The same authors described 46% as *oil absorption capacity* for quinoa flour, a property that decreased with salt addition (Ogungbenle *et al.*, 2009). Water and oil absorption are good, enhancing the potential of QS in human food and formulations like beverages, sauces, desserts, and sausages. Park and Morita (2005) studied the possibility of using germinated quinoa flour as a bioactive ingredient for applications in processing food like bread. The physical properties and baking quality of dough made from wheat flour with 10% ungerminated (control), and 24-, 48-, and 72-h-germinated quinoa flours were studied. They obtained bread of good nutritional quality, achieving an increase of the amount of free amino acids and a large loaf volume with the 24-h germinated quinoa flour. These results are useful for practical breadmaking, and the germinated quinoa flour may be applied as a useful food bioingredient. In this aspect, further studies of the nutritional value and sensory evaluation of germinated quinoa flour are needed for industrial applications in food processing (Park and Morita, 2005).

B. Functional properties of quinoa protein

Aluko and Monu (2003) studied the use of enzymatic hydrolysis to improve some functional properties of QPs. They found that *protein solubility* of the hydrolysate was over 80%, a value higher than that of protein concentrate. The protein concentrate (obtained by an alkaline method) had minimum solubility at pH 4–6 ($\pm$5%) and maximum solubility at alkaline pH (70%); Aluko and Monu (2003) also measured *foam expansion and stability* (expressed as %). Protein concentrate showed the smaller foam expansion (<20%), but protein hydrolysate presented values over 160%. Foam stability was better with protein concentrate.

The *emulsifying activity index and stability* were also measured by Aluko and Monu (2003), who found high stability for the hydrolysate, but a small activity index. The hydrolyzed proteins are not as adequate for food emulsions as the protein concentrate.

Abugoch *et al.* (2008) obtained two quinoa protein isolates (treated at pH 9 and 11) and studied solubility and the influence of pH. The minimum *protein solubility* was found in the pH 3–4 range. For the isolate (pH 9) about 77% at above pH 5, the other isolate (pH 11) presented 30% as maximum solubility. The WHC reported was similar for both isolates (around 3.5–5 mL water/g protein). Finally, the WIC was higher for the isolate treated at pH 11 (3.5 mL of water/g of isolate). Both isolates can be used as a good source of nutrition for infants and children; protein isolate (pH 9) may be used as an ingredient in nutritive beverages, and the other isolate (pH 11) may be used as an ingredient in sauces, sausages, and soups.

C. Functional properties of quinoa starch

Tang *et al.* (2002) measured the water absorption power of the starch granules of quinoa, and obtained a sigmoid sorption isotherm. Ahamed *et al.* (1996) and Lindeboom (2005) found lower solubility and viscosity for quinoa starch, and unusual freeze–thaw stability. Water binding capacity was reported by Lindeboom (2005) between 49.5% and 93%, values lower than those of corn starch (117%). Praznik *et al.* (1999) investigated some technological properties. Dependence of viscosity on temperature was determined for 5% (w/w) quinoa starch suspensions in the 55–95 °C range, and quinoa glucans disintegrate at 55 °C. The viscosity of 10% aqueous quinoa starch suspensions in Brabender (BU) was 1960 BU at 70 °C, comparable to waxy maize (1870 BU, 80 °C), and higher than wheat (910 BU, 45 °C) or amaranth (580 BU, 74 °C) (Praznik *et al.*, 1999). Quinoa starch may be used as a novel food source according to its properties (Watanabe *et al.*, 2007).

X. PRESENT AND FUTURE USES OF QS

Quinoa is well adapted to extreme weather conditions, and it is currently produced by Bolivia, Peru, Ecuador, Chile, Argentina, and Colombia. It is basically exported as dry and saponin-free quinoa, with Europe and the USA as the main consumers. Future uses can be wide-ranging, like textured and fermented products. There are many ways in which it can be consumed: cooked, AS flour, extruded. Quinoa meat substitute has been introduced in Europe (Tellers, 2008). There are several developments with quinoa flour at a smaller scale, like bread, cookies, muffins, pasta, snacks, drinks, flakes, breakfast cereals, baby foods, beer, diet supplements, and extrudates (Ahamed *et al.*, 1997; Bhargava *et al.*, 2006; Caperuto *et al.*, 2000; Chauhan *et al.*, 1992a,b; Dogan and Karwe, 2003; Linnemann and Dijkstra, 2002; Morita *et al.*, 2001). Coulter and Lorenz (1991) obtained extruded corn grits–quinoa blends that had high protein quality and solubility and an acceptable sensory evaluation. Caperuto *et al.* (2000) developed gluten-free quinoa spaghetti and obtained a product without loss of solids and acceptable weight and volume increase upon cooking, while the adhesiveness of the cooked product was not very high. The product was sensorially accepted by the panelists.

Quinoa flour does not have good baking properties like wheat gluten proteins. The wheat proteins are able to form a viscoelastic network when flour is mixed with water to form dough, and these viscoelastic properties allow the use of wheat to produce bread and other processed foods (Shewry *et al.*, 2002). Quinoa bread has been made by including 10% of wheat flour (Chauhan *et al.*, 1992a,b). However, the enzyme

transglutaminase (TGase) is promising for developing a protein structure, as reported by Kovács (2003). Use of the enzyme reduced the polypeptides of the low-molecular-weight fractions and the soluble protein fractions when producing pasta. There have been positive reports about TGase that induced crosslinking and polymerization of food proteins, such as milk proteins (Han and Damodaran, 1996), soy proteins (Sakamoto *et al.*, 1994), and fish proteins (Norziah *et al.*, 2008) to improve physicochemical properties. There are some gluten-free products without good baking properties for celiac groups, and quinoa provides an opportunity to develop gluten-free cereal-based products (Gallagher *et al.*, 2004). Dogan and Karwe (2003) showed that quinoa can be used to make novel, healthy, extruded, snack-type food products. They got a good product with maximum expansion, minimum density, high degree of gelatinization, and low water solubility index (16% feed moisture content, 130 °C die temperature, and 375 rpm screw speed). Quinoa has shown a high nutritional value and only recently is being used as a novel functional food. However, it is very important to increase and promote QS production, diversify production, and enhance its consumption. An important aspect to consider for promoting quinoa consumption is to inform consumers of the good properties of quinoa and let them incorporate it in their daily diet as a healthy, nutritious, good tasting, and versatile food. Alternatively, it is necessary to develop new functional products that can be available on the market for the ordinary user, and scale them up to industrial level.

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