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Nutritional Composition and Health Benefits of Golden Grain of 21st Century, Quinoa (*Chenopodium quinoa willd.*): A Review

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Abstract: Quinoa (*Chenopodium quinoa willd.*), a pseudo-cereal, has its origin from Andes region of South America. Its exceptional nutritional content, potential health benefits and crop's tolerance to adverse climatic conditions inspire nutritionists and researchers worldwide to explore more about this "wonder grain". Reviewers till now have focused on composition of this underutilized grain but extensive research work has now proved potential health benefits of quinoa. The present review covers recent research information on quinoa especially its potential health benefits to humans and also its nutritional content. Gluten free grain quinoa has been found to exhibit anti oxidative, anti hypertensive, anti diabetic properties hence can be used as nutraceutical and functional food ingredient.

Key words: Quinoa, nutritional content, health benefits

INTRODUCTION

The world food supply depends mainly on few crops species, termed as 'Major Crops'. Almost 95% of the world food requirement is met by 30 such crops. Because of this increased reliance on major food crops accompanied by shrinking of food basket (Prescott-Allen and Prescott-Allen, 1990), there is a great need to broaden the plant genetic diversity. Hence, researchers worldwide have brought forth the need to rescue and improve the use of crops left aside by research, technology and marketing systems. Such crops have been referred as "Neglected and Underutilized Crops" (NUCS) also known as "Orphan Crops". One such underutilized crop is *Chenopodium quinoa*, a pseudo cereal native to the Andean regions of South America (Matiacevich *et al*., 2006). Quinoa is a highly nutritious grain with a good content of quality protein, complete with essential amino acids, vitamins and minerals (Vilche *et al*., 2003).

According to Bogdan Debski *et al*. (2013) quinoa might be used not only as a good source of proteins and minerals but also as source of antioxidants. It has highest content of bioactive compounds compared to other cereals and pseudo-cereals (Hirose *et al*., 2010). According to the National Academy of Sciences of the United States, quinoa is considered among "golden grains" and because of its high nutritional value, NASA integrated it in the diet of astronauts (Carrasco and Soto, 2010). Taking into account potentially significant contribution of quinoa to fight against hunger and malnutrition, the thirty-seventh session of the General Conference of FAO declared year of 2013 as the International Year of Quinoa (United Nations, 2011).

Origin: Quinoa was domesticated initially back in 5000 B.C. (Uhle, 1919) in South America on high plateaus of Andes near lake Titicaca (Pearsall, 1992). Since then it has been an important staple food grain of Incas and is called *"chisiya mama"* meaning "Mother Grain" in their native language, Quenchua. According to FAO, Ecuador, Peru and Bolivia are the leading producers of quinoa (Taylor and Parker, 2002).

Morphology: Quinoa is annual dicotyledonous herbaceous plant usually about 1-2 m high (Franc and Martina, 2006). The seed is actually a fruit and has different colors (green, yellow, red or purple) and appearance depending on its variety (Koziol, 1993). It is disk-shaped (Imelda Prego *et al*., 1998) having flat equatorial band around its periphery. Quinoa differs from cereals in that the storage reserves for the developing embryo are found in the perisperm rather than in the endosperm, hence called as a pseudo cereal. The embryo that surrounds the perisperm (Fig. 1) is dicotyledonous and is part of the bran fraction of the seed (Varriano-Marsto and DeFrancisco, 1984; Becker and Hanners, 1990)

Areas of food reserves in quinoa seed: Areas of food reserves in quinoa seeds as revealed by Imelda Prego *et al*. (1998) are: perisperm, embryo and the endosperm.

Proximate composition: Quinoa (*Chenopodium quinoa willd.*) due to its exceptional nutritional and climate tolerance properties is now gaining popularity all across the world. Proximate composition of quinoa is given in Table 2.

There is significant difference seen in values of fiber as reported by Schoenlechner *et al*. (2008), Ramos Diaz and Martin (2011) as compared to those reported by Repo-Carrasco-valencia (2011) and Villa *et al*. (2014).

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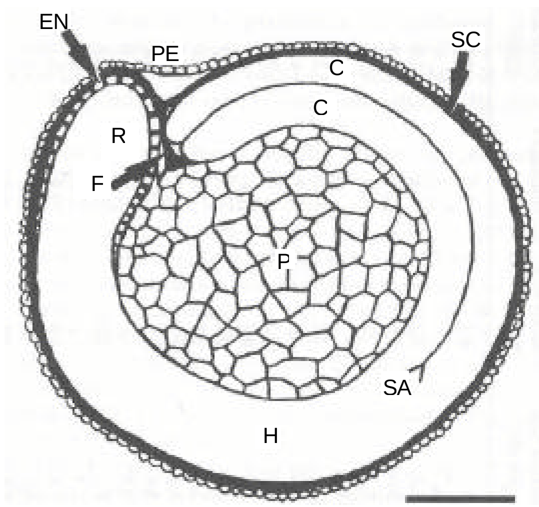

Fig. 1: Medial longitudinal section of quinoa seed showing the pericarp (PE), seed coat (SC), hypocotyl-radical axis (H), cotyledons (C), endosperm (EN) (in the micropylar region only), radicle (R), funicle (F), shoot appendix (SA) and perisperm (P) (Imelda Prego *et al*., 1998)

This is because the values reported by others are of crude fiber, which is always less than total dietary fiber. Among different anatomical parts of quinoa, Becker and Hanners (1990) (Table 2) reported highest proximate composition of quinoa bran.

Proteins: Koziol (1992) reported high protein content in quinoa grain which ranges from 13.8 to 16.5%, with an average 15%. Protein content of 14.8% for sweet quinoa varieties (having less amount of saponin) and 15.7% for bitter quinoa varieties (having more saponin) from Bolivia has been reported (Wright *et al*., 2002). De Bruin, 1963 studied four genotypes of quinoa, reporting protein range of 12.9-15.1%. Lysine content of quinoa is double as compared to wheat. In addition, the sulfur-containing amino acids cystine and methionine are found in concentrations that are unusually high compared to other plants, (Schlick, 1996) probably due to the type of land (volcanic) where this plant originated. Quinoa flour is low in gluten due the low contents of prolamines and glutamines and this makes it suitable to be consumed by patients suffering from celiac disease.

Carbohydrates: Starch is the main carbohydrate in quinoa, located in primarily the perisperm (Imelda Prego *et al*., 1998). It makes up approximately 58.1-64.2% of the dry matter, of which 11% is amylose (Repo-Carrasco *et al*., 2003) Quinoa starch granules are smaller in size than that of common cereals, having a polygonal form with a diameter of 2 µm. Being rich in amylopectin, it has excellent freeze-thaw stability (Berghofer and Schoenlechner, 2002) and thus is an ideal thickener in frozen foods and other applications where resistance to retrogradation is desired (Ahamed *et al*., 1998).

Fat: Fat, mainly located in the embryo of quinoa grain (Prego, 1998), is found to be higher than that of maize (3-4%) ranging from 1.8 to 9.5%, with an average of 5.0-7.2% (Koziol, 1992). Dini *et al*. (1992) reported 14.5% total lipid content in quinoa with about 70% unsaturated fatty acids (linoleic and oleic acids in percentages of 38.9 and 27.7%, respectively). Linoleic acid (52%) is the most abundant polyunsaturated fatty acid identified in quinoa (Ahmed *et al*., 1998). All fatty acids present in quinoa are well protected by the presence of vitamin E, which acts as a natural antioxidant (Huber *et al*., 2007). Also, quinoa's n-6/n-3 ratio, at 6.2, falls within the recommended values (Alvarez-Jubete *et al*., 2010).

Nutritional composition

Minerals: Minerals in quinoa are found in outer bran layers (Imelda Prego *et al*., 1998) at concentrations greater than that reported for most grain crops. Iron (81 mg/kg), calcium (874 mg/kg) and phosphorus levels are higher in quinoa than those of maize and barley (Ahmed *et al*., 1998b). Minerals like phosphorous, potassium and magnesium are located in the embryo of quinoa, while Ca and P in the pericarp are associated with pectic compounds of the cell wall (Konishi *et al*., 2004). Sulfur is found uniformly distributed within the embryo of quinoa. Iron in quinoa has been reported as highly soluble and thus could be easily available to anemic populations (Valencia *et al*., 1999).

Vitamins: Vitamins are essential nutrients required in small amounts by organisms. Koziol (1992) reported that quinoa has substantially higher vitamin content as compared to common cereals (rice, barley and wheat). In terms of a 100 g edible portion, quinoa supplies 0.20 mg vitamin B6, 0.61 mg pantothenic acid, 23.5 g folic acid and 7.1 g biotin (Bhargava, 2006). Presence of significant amount of α-tocopherol enhances its antioxidant properties. Beta carotene concentrations (0.39 mg/100 g dry weight) in quinoa have been found to be higher as compared to cereals like wheat (0.02 mg/100 g dry weight) and barley (0.01 mg/100 g dry weight) (Koziol, 1992)

Recently, Schoenlechner *et al*. (2008) quinoa has been found to contain folate content (132.7 mg/100 g dm) ten times more than that in wheat. The bran fractions contained on average 124% of total folate, while only 57% on average was present in the flour fractions. According to their study quinoa based products (bread, pasta and cookies) are a great alternative for folate intake.

Dietary fibre: The generally used classification for dietary fiber is: total, soluble and insoluble fiber. Total, insoluble and soluble dietary fiber content of different

Table 1: Areas of food reserve in quinoa grain

Prego *et al.* (1998)		
Method of analysis	Area of food reserve	Food reserve
Cytochemical and ultrastructural analysis	Perisperm	Starch Grains
	Cells of the endosperm and embryo tissues	Lipid bodies, protein bodies with globoid crystals of phytin and proplastids with deposits of phytoferritin
EDX analysis	Endosperm and embryo protein	Phosphorus, potassium and magnesium

Table 2: Proximate composition of quinoa seed

Proximate composition	Schoenlechner *et al.*, (2008)	Repo-Carrasco-valencia (2011) (g/100 gm)	Ramos Diaz and Martin (2011) (g/100 gm)	Villa *et al.* (2014)
Moisture (%)	-	10.78-12.62	11.6	14.7
Ash (%)	3.33	13.96-15.47	3.2	3
Protein (%)	13.8	3.04-5.46	16.4	11.7
Fat (%)	5.04	4.69-6.85	6.3	12.4
Carbohydrate	69	68.84-75.82	63	55.3
Crude fiber (%)	12.88**	1.92-3.38	11.5**	2.2

**TDF: Total dietary fiber

Table 3: Proximate composition of anatomical parts of quinoa (Becker and Hanner, 1990)

	Becker and Hanner (1990)			
	Ash	Crude protein	Lipid	TDF
Whole	2.6-3.0	11.0-13.7	6.0-6.6	1.1-1.8
Bran	5.7-6.8	22.3-32.2	14.2-17.8	1.2-1.7
perisperm	0.8-1.4	4.8-7.4	1.0-2.8	0.6-1.0

TDF: Total dietary fiber

Table 4: Amino acid content of quinoa

	Koziol (1992)	-------- Repo-Carrasco (1992) --------		
Amino acid	Quinoa	Quinoa	Rice	Wheat
Histidine	3.2	2.7	2.2	2.0
isoleucine	4.4	3.4	3.5	4.3
leucine	6.6	6.1	7.5	6.7
lysine	6.1	5. 6	3.2	2.8
Methionine+cystine	4.8	3.1	3.6	1.3
Phenylalanine+tyrosine	7.3	2.5	2.6	3.7
threonine	3.8	3.4	3.2	2.9
tryptophan	1.1	1.1	1.2	1.2
valine	4.5	4.2	5.1	4.6

Table 5: Mineral content of quinoa (mg/100 g)

Mineral	Konishi *et al.* (2004)	Alvarez-Jubete *et al.* (2010)	Miranda *et al.* (2010)
Calcium	86.9	32.9	56.5
Magnesium	502	206	176
Phosphorous	411	nd	468.9
Iron	15.0	5.5	14.0
Potassium	732	nd	1193.0

Nd: not determined

Table 6: Vitamin content of quinoa

Vitamin	Ruales and Nair (1994)	Alvarez-Jubete *et al.* (2010)
Thiamine (mg/100 g)	0.4	nd
Riboflavin (mg/100 g)	0.2	nd
Folic acid (μg/100 g)	78.1	nd
Vitamin C (μg/100 g)	16.4	nd
Alpha-tocopherol (mg/100 g)	2.6	24.7
Vit A (mg RE/100 g)	0.2	nd

varieties of quinoa (raw) as reported by Repo-Carrasco-Valencia (2011) is given in Table 7. The soluble fibre content is similar to, that of rye, while the insoluble fibre content was slightly lower and both are higher than that of wheat. Extrusion of quinoa seeds and eliminating the bitter substances, saponins, of quinoa, also decreases the fiber content (Repo-Carrasco-Valencia, 2011; Alvarez-Jubete *et al.*, 2009).

Sugars: Valencia-Chamorro (2003) reported 2% monosachhrides and 2.3% disaccharides in quinoa. Quinoa flour contains high percentages of D-xylose and maltose and low contents of glucose and fructose, which allows its use in malted drink formulations (Ogungbenle, 2003). Also, it's content of D-ribose and D-galactose and maltose result in a low fructose glycemic index.

Phytochemical composition

Polyphenols: Quinoa seeds have been found as a good source of bioactive-polyphenols prevent oxidative stress and have potential to change antioxidant status of organism (Paskol *et al.*, 2008). The main phenolic acid found both in seeds and sprouts of quinoa and red amaranth was gallic acid. p-Hydroxybenzoic acid, vanillic acid, p-coumaric acid, caffeic acid and cinnamic acid were also found in the seeds and p coumaric acid, syringic acid and ferulic acid in the sprouts (Paskol *et al.*, 2008). Gorinstein *et al.* (2007) reported that the total phenolic content of quinoa was 60 mg GAE/100 g of grain. The total phenol content of quinoa was significantly higher than amaranth, lower than buckwheat ($p<0.01$) and statistically not different from wheat, order being: buckwheat>quinoa>wheat> amaranth (Alvarez-Jubete *et al.*, 2010).

Flavonoids: Quinoa has exceptionally high flavonoid content varying from 36.2 to 144.3 mg/100 g (Repo-Carrasco-Valencia *et al.*, 2011). Martinez (2009), found that isoflavones particularly daidzein and genistein are found in different concentrations in quinoa from different

Table 7: Fiber content of quinoa

	Repo-Carrasco-Valencia (2011)		
	IDF	SDF	TDF
Quinoa	11.99-14.39	1.41-1.6	13.56-15.99

IDF: Insoluble dietary fiber SDF: Soluble dietary fiber
TDF: Total dietary fiber

Table 8: Sugar content in quinoa

Sugar content in Quinoa (g/100 g dry matter) (Repo-Carrasco, 1992)			
Glucose	Fructose	Sucrose	Maltose
1.70	0.20	2.90	1.40

origins. Germination followed by subsequent oven drying increases flavonoid content of quinoa to 4.4 folds (Carciochi *et al*., 2014).

Phytic acid: Phytic acid is another disadvantageous factor present in quinoa as it binds minerals, resulting in formation of respective phytates thereby rendering them unavailable for metabolism (Khattak *et al*., 2007). Unlike as in the case of rye and wheat, it is not only present in the outer layers of the seed but is also evenly distributed in the endosperm (Ahamed *et al*., 1998). Ruales and Nair (1994) and Koziol (1992) reported that phytic acid in quinoa seeds is approximately 0.7 to 1.2% (of dry matter) which can be reduced upto 30% by soaking and germination (Valencia *et al*., 1999).

Oxalates: The highest oxalate content is found in leaves and stems. Jancurova *et al*. (2009) reported that soluble oxalate content ranged from 59 to 131 mg/100 g in roots and nuts and from 258 to 1029 mg/100 g in leaves and stems. According to Siener *et al*. (2006), total oxalate content ranged from 143 to 232 mg/100 g in roots and nuts and from 874 to 1959 mg/100 g in leaves and stems.

Tannins: Tannins are present in small amounts (0.53 g/100 g in the whole quinoa seeds) which are further reduced after scrubbing and washing with water (0.23 g/100 g) (Valencia-Chamorro, 2003).

Saponins: Saponins are the primary limiting factors associated with quinoa giving it a bitter taste (Improta and Kellems, 2001). The epicarp surrounding the seed contains saponins which give it a characteristic bitter or astringent taste (Tarade *et al*., 2007). Chauhan *et al*. (1992) reported that 40-45% of the saponins were present in the hulls. The content of saponins as reported by Stuardo and San Martin (2008) varies in quinoa between 0.1 and 5%. Quinoa has been classified on the basis of saponin content present as 'sweet' (free from or containing <0.11% of free saponins) or 'bitter' (containing >0.11% of free saponins) (Martinez *et al*., 2009). Although saponins have been referred as "anti nutrient of quinoa", it could also have nutritional or pharmacological benefits. Antifungal activity of quinoa saponins has been reported by Stuardo and San Martin (2008); as it causes damage to fungal membrane integrity by associating with steroids of fungal membranes.

In vitro digestibility tests

Protein *in vitro* digestibility: The protein in quinoa is of an exceptionally high quality and is particularly rich in histidine and lysine. The *in vitro* digestibility of protein of the four extruded quinoa varieties studied by Repo-Carrasco-Valencia (2011) was between 76.3 and 80%. The digestibility of quinoa protein was found to be comparable to that of other high quality food proteins (Comai *et al*., 2007).

Starch *in vitro* digestibility: As a protein matrix surrounds starch granules of quinoa, they are not very easily hydrolyzable by α-amylase. Treating quinoa flour with proteolytic enzymes prior to hydrolysis with α-amylase can improve the degree of starch hydrolysis. According to Ruales and Nair (1994) starch *in vitro* digestibility of raw, autoclaved, cooked were 22, 32 and 45%, respectively which was lower than as reported by Repo-Carrasco-Valencia (2011) in different varieties of quinoa (65.11-68.53%).The value of starch *in vitro* digestibility of drum dried quinoa reported by Ruales and Nair was higher (73%).

Therapeutic benefits

Gluten Free grain for celiac patients: Celiac disease (CD) also known as gluten intolerance, is a gluten sensitive inflammatory disorder of the small intestine which affects individuals when they ingest gluten proteins from wheat, barley and rye. Quinoa is found to lack gluten (Leite Olivera, 2008; Perez *et al*., 2009) and is well tolerated by patients suffering from gluten intolerance (Zevallos *et al*., 2014).

Antioxidant properties (*In vitro*): Seeds of quinoa (*Chenopodium quinoa willd*.) are an excellent source of the free-soluble antioxidant fraction (Laus *et al*., 2012). Among Peruvian Andean grains (five cereals, three pseudo cereals and two legumes), Ranilla *et al*. (2009) reported highest antioxidant activity (86%) of quinoa. Red quinoa seeds, have been found to have significantly higher levels of TPC (Total Phenolic Content), TFC (Total Flavonoid Content) and FRAP (Ferric Reducing Antioxidant Potential) than yellow quinoa seeds and thus can be helpful in prevention or management of degenerative diseases associated with free radical damage (Yael Brend *et al*., 2012). Germination and subsequent oven-drying increases antioxidant activity of quinoa seeds, by 2 folds (Carciochi *et al*., 2014). Pawel Pasko *et al*. (2010) conducted a study to see the effect of diet supplemented with quinoa seeds on oxidative status in plasma and selected tissues of high fructose-fed rats. Quinoa (310 gm/kg fodder) was found to act as moderate protective agent against changes caused fructose induction such as increase in plasma monodialdehyde (MDA) by reducing lipid peroxidation and enhancing the antioxidant capacity of the blood (plasma), heart, kidney, testis, lung and pancreas.

Anti-obesity activity (*in vivo*): Foucault *et al.* (2012) conducted a short period experiment with quinoa extract enriched in 20-hydroxy ecdysone on rats with diet-induced obesity. Beneficial effects on fat mass were observed. The findings indicated that the extract acts by reducing both fatty acid uptake and esterification in adipocyte.

Hypocholesterolemic effect (*in vivo*): Hypocholesterolemic effect of the quinoa pericarp can be attributed to the water-soluble dietary fiber content, as in oat, rice bran or other fibers. Konishi *et al.* (2004) reported that a 3% quinoa pericarp supplemented diet significantly decreased serum and liver cholesterol levels in mice. Takao *et al.* (2005) extracted protein fractions from quinoa seeds. Mice were fed on 0.5% cholesterol diet containing 0, 2.5 and 5% of quinoa protein (QP) for 4 weeks. QP supplementation significantly prevented the increase in plasma and cholesterol levels. Pawel Pasko *et al.* (2010) studied the effect of *Chenopodium quinoa* seeds on lipid profile, glucose level, protein metabolism and selected essential elements (Na, K, Ca, Mg) level in high fructose fed male wistar rats. The analysis of blood of rats fed with quinoa indicated, that these seeds effectively reduced serum total cholesterol (26%), LDL (57%, $p<0.008$), triglycerides (11%, $p<0.05$), glucose (10%, $p<0.01$) and plasma total protein level (16%, $p<0.001$) when compared to the control group. Quinoa seeds did not prevent any adverse effect of increasing triglyceride level caused by fructose.

Farinazzi-Machado (2012) conducted a study to investigate the effects of quinoa on the biochemical and anthropometric profile and blood pressure in humans, parameters for measuring risk of cardiovascular diseases. Reductions in levels of total cholesterol, triglycerides and LDL-C were seen. It was concluded that the use of quinoa in diet can be considered beneficial in the prevention and treatment of risk factors related to cardiovascular diseases.

A prospective and double-blind study was conducted by De Carvalho (2013) on 35 women with weight excess who consumed 25 g of quinoa flakes (QF) or corn flakes (CF) daily during a period of four consecutive weeks. The reduction of total cholesterol (191±35 to 181±28 mg/dL) and LDL-cholesterol (LDL-c) (129±35 to 121±26 mg/dL) and the increase in GSH (1.78±0.4 to 1.91±0.4 µmol/L) occurred only in the QF group, showing a possible beneficial effect of QF intake.

Conclusion: Quinoa, the ancient Andean grain, with exceptional nutritional profile also has its potential health benefits. Presence of Lysine, an amino acid lacking in all other cereals makes it unique among all cereals. High dietary fiber and polyunsaturated fatty acids with good stability increases its potential to treat obesity, hypercholesterolemia and cardiovascular disorders. Its natural antioxidants such as phenolic compounds are helpful in treatment of degenerative diseases. Due to absence of gluten, it is tolerable and acceptable to celiac patients. It can be used in daily diets in form of breads, cookies, pasta, salads for adopting a healthy lifestyle. With exceptionally high nutritional sprofile, resistance to adverse climatic conditions, potential to diversify shrinking food basket, fighting hunger and malnutrition world over and potential health benefits the grain proves itself to be wonder grain.

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