Mysore J. Agric. Sci., 55 (1) : 1-8 (2021)

Quinoa (*Chenopodium quinoa* Willd.) A Climate Resilient Wonder Grain : A Review

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ABSTRACT

Quinoais an ancient pseudo-cereal which was cultivated in the Andean region since 3000 B.C. It is called as Mother of all grains because of its high nutritional value particularly for people with gluten intolerance. Its protein is exceptionally high in lysine which is not abundant in other plants. It is also a good source of methionine and cystine which are low in legumes. Quinoa has high content of health beneficial phytochemicals, including amino acids, fiber, polyunsaturated fatty acids, vitamins, minerals, saponins, phytosterols, phytoecdysteroids, phenolics, betalains and glycine betaine. It is drought tolerant crop with plasticity in the adaptation to different environmental conditions. It has greater plasticity of adaptation to photo period, altitude, soil pH etc. It can be used to make novel, healthy, extruded, snack-type food products. It is usually used to enhance baking flours in the preparation of biscuits, noodles, pastries and for the preparation of baked foods to maintain the moisture and give an agreeable flavor. There is a lack of information on production, nutritional quality, consumption and utilization of quinoa plant products and these are the main constraints to bring this crop under cultivation. Consumption of quinoa (about 40 g) meets daily recommendations for essential nutrients and health-improving compounds as it offers an excellent nutritional quality and has a high commercial value.

Keywords: Adoptability, Quinoa, Health benefits, Novel snack food, Nutritional, Pseudo-cereal

QUINOA (*Chenopodium quinoa* Willd.) also called Mother of all grains is a potential pseudo-cereal native to Andean region of South America. It is an annual herbaceous plant belonging to Amaranthaceae family, but formerly placed in Chenopodiaceae family that originated in the Pacific slopes of the Andes in South America. It was cultivated and used by the *Inca* (ruling class) people since 5000 B.C. The main quinoa producing countries are Bolivia, Peru, Ecuador and Chile (Coral and Cusimamani, 2014). Nowadays, this crop is cultivated in South America, USA, China, Europe, Canada and India. It is cultivated in the world in an area of 126 thousand hectares with a production of 103 thousand tonnes. Bolivia in South America is the largest producer of quinoa (46 %) in the world followed by Peru (42 %) and United States of America (6.3 %) (FAOSTAT, 2013).

Quinoa (pseudo-cereal) is one of the oldest crops in Andean region with approximately 7000 years of cultivation history. Great cultures like the Incas had domesticated and conserved this ancient crop (Jacobsen, 2003). In 1996, quinoa was catalogued by FAO as one of the most promising crops for the humanity because of its great properties and multiple uses. It is also considered as an option to solve human nutrition problems (FAO, 2011). The quinoa plant was widely cultivated in the whole Andean region in Columbia, Equator, Peru, Bolivia and Chile before the Spanish conquest. However, the habits and traditional foods of natives were replaced with foreign crops such as Wheat and Barley. Therefore, quinoa was cultivated either in small plantations in rural areas for domestic consumption or as border crop for other crops such as potatoes or maize. For this reason, it was classified as food for poor people (Valencia-Chamorro, 2003). In order to recognize ancestral practices of Andean people, the United Nations General Assembly declared year 2013 as 'The International Year of Quinoa' (Bavec and Bavec, 2006). Nowadays there is an increased interest in quinoa crop because its seed contain high quality protein and they are balanced in respect of amino acid composition as compared to most of the available cereal grains. Quinoa grains are rich source of dietary fiber, vitamins, minerals and natural antioxidants. It has been observed by the Food and Agricultural Organization (FAO) that quinoa has ideal balance of amino acids than any other grain. The protein in quinoa grain is as good in quality as that in cow's milk.

In India, quinoa is successfully grown in Hyderabad and Ananthapuram districts of Andhra Pradesh. It grows naturally in Himalayan regions of India. It is cultivated in an area of 440 hectares with an average yield of 1053 tonnes (Srinivasa Rao, 2015). Andhra Pradesh and Uttarakhand are emerging as the main cultivating area of quinoa in India. In 2013, Uttarakhand reportedly signed a horticulture research agreement with Peru to grow quinoa in the state and the research institutes in Andhra Pradesh have successfully developed local varieties of the crop. As part of crop diversification efforts, in Rajasthan 50,000 farmers have taken-up quinoa cultivation in 2017-18. Rajasthan State Seeds Corporation engaged some farmers to grow this crop on experimental basis and managed to raise more than 20,000 quintals of seed. The government had identified eleven districts that were suitable for growing this highly nutritive grain. In Punjab few farmers in Fazilka district, adjoining Rajasthan border also cultivated quinoa for the first time in 2017-18. A well educated farmer in Ludhiana district of Punjab has been growing this crop for the last two years. Cultivation of quinoa can be promoted in Karnataka as it has the potential to serve as an integral component of crop diversification. In Ananthpur of Andhra Pradesh state, a progressive farmer Mr. Shivashankara Reddy has taken up quinoa cultivation in an area of more than 40 hectares and earned good income by producing and marketing processed quinoa seeds which became the first in the whole of the country. It motivated so many farmers to venture and to cultivate this crop. In Karnataka, many farmers are showing interest to grow this crop because of its nutrient content. The traders from Bengaluru also interested to buy organic quinoa from the farmers for export to the European countries where there is huge demand. In this context, there is huge scope to grow this crop organically and definitely farmers will get more income out of this crop in coming years. We need to diversify the agro-ecosystem for nutritional security and environmental sustainability. Quinoa is such a crop which can tolerate heat and drought and hence it is suitable for aberrant weather situation.

Nutritional Profile

The effects of globalization and urbanization have influenced dietary patterns and lifestyle behaviors among population groups throughout the world. Traditional food patterns which are rich in complex carbohydrates, micronutrients, fiber and phyto-chemicals are being replaced with diet high in animal fats, refined carbohydrates and oils, which made a direct impact on the prevalence of certain chronic diseases (Schaffer-lequart *et al.,* 2015). For this reason, many researchers devoted their efforts for analyzing food or food components that proved to be healthy for human consumption (Jancurova *et al*., 2009). Work of Health grain consortium included quinoa in its list of healthy grains (Vander Kamp *et al*., 2014). In comparison to most cereals, quinoa seeds have a higher nutritional value (Matiacevich *et al*., 2006).

Protein

The protein content of quinoa seeds varies from 8 to 22 per cent which is higher than that in common cereals such as rice, wheat and barley. In quinoa most of the protein is located in the embryo which contains higher amount of lysine, methionine and cysteine and act as a good complement for legumes, which are deficient in methionine and cysteine (Valencia-Chamorro, 2003 and Repo-Carrasco *et al.,* 2003). The nutritional evaluation of raw quinoa has reported protein efficiency ratio (PER) of 78-93 per cent that of case in and was found greatly improved after cooking (Valencia-Chamorro, 2003). As per the FAO/WHO pattern suggested for pre-school children, quinoa containing all essential amino acids with no deficiency of any of them considered to have the best amino acid profile. It is also good source of histidine, isoleucine, phenyl alanine, tyrosine, leucine and tryptophan contents (Beatriz and Suzana, 2012).

Lipid

The lipid content of quinoa ranges from 5.2 to 9.7 per cent which is approximately two times higher than that of maize and wheat (Alvarez-Jubete *et al*., 2010) and the fat content ranges from 2-10 per cent. The high lipid content and the fatty acid profile of quinoa found similar to that of maize and soybean oil and it is a suitable alternative for oilseeds (Koziol, 1992). The most abundant fatty acid in quinoa is linoleic acid (omega-6) ranging from 48.2 - 56.0 per cent followed by oleic acid ranging from 24.5 - 26.7 per cent and palmitic acid ranging from 9.7 - 11.0 per cent, constituting 14 per cent of total fatty acids (Beatriz and Suzana, 2012 and Alvarez Jubete *et al*., 2009). Inspite of high amount of lipids, quinoa lipids are stable against oxidation because of the α-tocopherol (Vitamin-E 0.59 - 2.6 mg/100g) which is naturally occurring in it (Schoenlechner *et al*., 2008 and Riyan *et al*., 2007).

Carbohydrate

The starch content of quinoa ranges from 58.1 to 64.2 per cent with a granular diameter of 2 µm and is smaller than the size of starch of common grains (Repo-Carrasco *et al.,* 2003). The amylose content ranging from 3.5 - 22 per cent found in quinoa starch (Schoenlechner *et al*., 2008). Gelatinization temperature of quinoa ranges from 55.5 - 72.0 ^{0}C and contains free sugars in small quantities (Repo-Carrasco *et al*., 2003). About 12.88 to 14.20 per cent dietary fiber is present in quinoa particularly in the embryo (Beatriz and Suzana, 2012) and its soluble fiber can be reduced by cooking and autoclaving without affecting insoluble fiber (Ruales and Nair 1994).

Minerals

Quinoa is a good source of minerals which is about two times of the mineral content in cereals. However, Ca, Mg, Fe, and Zn are found in fairly high amount in quinoa (Repo-Carrasco *et al*., 2003). Gluten free diets are generally deficient in Ca, Mg and Fe and the use of quinoa can be promoted as an aid to reduce the deficiency as it is found to be rich in these elements (Alvarez-Jubete *et al*., 2010).

Vitamins

The composition of vitamins in quinoa resembles that of cereals (Taylor and Parker, 2002). Adequate amount of thiamine varying from 0.29 to 0.36 per cent, riboflavin ranging from 0.30 - 0.32 per cent, vitamin B6 0.48 per cent and total folate 0.18 per cent are present in quinoa, while niacin level found was very low. Ascorbic acid found in quinoa varies from 4.0 to 16.4 mg/100 g (Koziol, 1992). Quinoa grains are stable towards oxidation owing to the presence of vitamin E and vitamin C which acts as potential antioxidants (Riyan *et al*., 2007).

Bioactive Compounds

Saponin asteroid and triterpenoid glycoside found in various plant species (Repo-Carrasco *et al.,* 2003). They are the major anti-nutritional factors in quinoa with their values ranging from 0.2 - 0.4 g/kg in bitter types (Masterbroek *et al.,* 2000) and concentrated mostly in the pericarp that gives it a bitter taste (Repo-Carrasco *et al*., 2003). Threshold value for the bitter taste in quinoa is 100 mg /100 g (Taylor and Parker, 2002). It can be eliminated either by dry methods (toasting and subsequent rubbing of the grains to remove the outer layers) or by washing and rubbing in cold water (Risi and Galwey, 1984). It is also a very good source of flavonoids which comprise mainly of glycosides of flavonoids, kaempferol and quercetin (Dini *et al*., 2004). The antinutritional factor of phytic acid has been reported to be present ranging from 0.7 to 1.2 per cent (Ruales and Nair, 1994 and Koziol, 1992) which can be reduced up to 30 per cent by soaking and germination (Valencia *et al*., 1999).

Adaptability of Quinoa to Varied Climatic Conditions

It shows enormous variation and plasticity in its adaptation to different environmental conditions and is cultivated from sea level to 4000 above msl. It is tolerant to adverse climatic factors such as drought, frost, soil salinity and others that affect the crop. Its growing season ranges from 90-240 days. It grows with the precipitation ranging from 200-280 mm per year. Though quinoa prefers neutral soils, it is usually grown on alkaline soils up to pH of 9.0 and acidic soils up to pH of 5.0. It also thrives in sandy and clay soils. The ideal temperature for quinoa cultivation is around 18 °C to 20 °C, although it can with stand temperature extremes ranging from 39 °C to -8 °C. It has greater plasticity of adaptation to photo period, altitude, soil pH etc. Quinoa seems to be a quantitative short-day species where in the length of the vegetative period depends not only on the day length and latitude of the origin but also on altitude of the origin (Rishi and Galwey, 1984). The adaptability of quinoa to varied levels of drought is due to the differentiation of a diversity of ecotypes originating in contrasting agro-environments. Plants display various adaptive strategies to drought stress, from morphological to physiological adaptations that serve a range of responses to water deficit, from avoidance to resistance and tolerance. Plants copeup with the drought stress by changing and modifying key physiological processes such as photosynthesis, respiration, water relations, antioxidants and hormone metabolism. Whole-plant responses to drought involve changes in leaf and root growth, in some cases with strong ontogenetic variation. These drought responses at both physiological and morphological levels show intraspecific variation related to ecotype differentiation. Quinoa thus represents an invaluable opportunity, both as a potential crop in consideration of present and future climate change challenges and as an important source of genes with biotechnological applications (Azurita-Silva Andres *et al*., 2014).

Value Added Products of Quinoa and their Utilization

Similar to rice, its seeds are consumed in soups, by puffing them to make breakfast cereals or by flouring them to produce baked products like cookies, bread, biscuits, pasta, crisps, tortilla and pancake (Bhargava *et al*., 2006). In addition, quinoa seeds can be fermented to make beer or a kind of traditional alcoholic drink used for religious ceremony called chichi in South America (FAO, 2011). Gluten free spaghetti type product can also be produced using quinoa and corn (Caperuta *et al.,* 2001). Gluten free pasta was produced using buck wheat and quinoa (Schoenlechner *et al*., 2004). Popped or extruded amaranth and quinoa were used to produced granola bars and muesli with good sensory characteristics (Wesche *et al*., 1996). Quinoa can also be used as a rice displacement, hot breakfast cereal and in infant food. Solid state fermentation of quinoa with *Rhizopus oligosporus saito* provides a good quality tempeh (Valencia-Chamorro, 2003).

Quinoa flour can be mixed with maize or wheat flour. Several levels of quinoa flour substitution have been reported. For instance in bread (10-13 % quinoa flour), noodles, pasta (30-40 % quinoa flour) and sweet biscuits (60 % quinoa flour) (Valencia-Chammoro, 2003). The seeds are boiled like rice or used to thicken soup or as porridge. Quinoa flour can be made into noodles. It is complicated due to the bitter taste of seeds because of their saponin content which forms a soapy solution in water. Studies on the stability of vanillin entrapped within the spherical aggregates obtained from Amaranth (*Amaranthus paniculatus* L.), Quinoa (*Chenopodium quinoa* wild), Rice (*Oryza sativa* L.) and Colocassia (*Colocassia esculenta* L.) in the presence of Arabic gum, carboxy methyl cellulose (CMC) and Carrageenan at 0.1-1.0 per cent as bonding agents were carried out using spray drying of 20 per cent starch dispersion at 120 per cent. Vanillin was used at 5 per cent based on starch (Tarai *et al*., 2003).

Beverages were prepared from raw, soaked, germinated and malted quinoa seeds and investigated their antioxidant, anti-diabetic and anti hypertensive potential using *in-vitro* model (Kaur and Tanwar, 2016). Preparation of Pasta by replacing 20 per cent of semolina with native and fermented quinoa flour was found to have more (twice) amount of free amino acids, total phenols and the antioxidant activity than the other types of pasta (Lorusso *et al.,* 2017). Prepared gluten free tarhana by using different ratios (40:30:30, 50:25:25, 60:20:20 %) of quinoa flour, rice flour and potato starch instead of wheat flour indicated that quinoa flour affected the colour of gluten free tarhana (Demir, 2014).

Health Benefits of Quinoa Grain

The number of clinical studies regarding the effects of quinoa consumption on human health is quite low.

Childhood nutrition study performed in 50-65 month-old boys in low-income families in Ecuador found that 100 g consumption of quinoa-added baby food twice a day for 15 days significantly increased the plasma insulin-like growth factor (IGF1) levels in kids, when compared to the control group. It was determined in this study that baby food with quinoa provided sufficient protein and other essential nutritional elements which have a key role in preventing malnutrition among kids (Ruales and Nair, 1994).

The study aimed at investigating *in-vivo* effects of quinoa consumption among adults with celiac disease. Nineteen celiac patients under treatment were made to consume 50 g of quinoa every day for six weeks as part of a gluten-free diet and the diet serology and gastro intestinal parameters were evaluated. The results indicated that the individuals' gastro intestinal parameters were normal. The rate of villus height to crypt depth was slightly lower (2.8:1) than the normal values at first but this value reached a normal level (3:1) at the end of the study. Quinoa addition to a gluten-free diet in celiac patients was well tolerated and did not deteriorate the disease. Improved histological and serological parameters and a positive tendency towards especially mild hypocholesterolemic effect were identified (Zevallos *et al*., 2014). This study revealed the first clinical data that showed the daily consumption of 50 g of quinoa over a six-week period was safely tolerated by celiac patients. Still, there is a need for further studies to determine the long-term effects of quinoa consumption.

Another study revealed that daily consumption of quinoa candies by 22 students aged between 18 and 45 for 30 days considerably reduced their triglyceride, total cholesterol and LDL levels. In addition, their values regarding blood glucose, body weight and blood pressure reduced but the decrease was statistically insignificant (Farinazzi-Machado *et al*., 2012).

In a different study carried out with 35 postmenopausal overweight women who consumed 25 g of quinoa flakes and cornflakes every day for four weeks successively found that statistically significant decrease in their serum triglyceride, TBARS and vitamin E levels while, there was a statistically significant increase in urinary secretion of enterolignans in both groups (De Carvalho *et al*., 2014). However, in another study that investigated the effects of quinoa, amaranth and Kaniwa consumption on weight gain and Type 2 diabetes, 110 middle-aged individuals (22 diabetic and 88 non-diabetic people) were observed and it was observed that individuals with normal body-mass index consumed these grains more often than those who were overweight or obese. It was also found that the individuals with diabetes consumed these grains more often and flour less often than those who were non-diabetic (Sanchez, 2012).

In a double-blind placebo controlled clinical study carried out with men with an average age of 20.5 ± 3 who voluntarily did resistant exercise for three times a week for at least one year, the results revealed that 30 mg/day 20 HE supplementation for an eight-week period neither affected body composition, anabolic/catabolic hormone status (free and active testosterone, and cortisol) or universal indicators of catabolism nor provided a significant improvement in performance. Inclusion of only nine people in each group and 8-week implementation of 20 HE was the limitations of this study. The study also claimed that the effect of 20HE on performance could be stronger in inexperienced individuals as opposed to experienced sports people (Wilborn *et al*., 2006).

It was reported that one serving of quinoa consumption (about 40 g) meets an important part of daily recommendations (RDA) of essential nutrients and health-improving compounds as it offers an excellent nutritional quality and has a high commercial value. Further, it is thought that more research is needed to increase individuals' awareness of this pseudo-grain's nutritional content and consumption, to reveal its nutritional benefits and to investigate its effects on health (Graf *et al*., 2015).

Constraints and Strategies to Promote Quinoa Cultivation in India

There are many difficulties in popularizing quinoa at market and consumer level because of variety of reasons namely;

- Basically, most of the farmers are unaware about the crop, its mode of usage, nutritional quality and mode of storage
- All the farmers in the country consider the commercial benefits to grow any crop not nutritional benefits to their own family
- Lack of information on production, nutritional quality, consumption and utilization of quinoa plant products
- Lack of awareness on economic benefits and market opportunities
- Lack of technology for value addition through village level food processing
- Lack of improved quality seeds
- Lack of producer interest
- Low yield
- Post-harvest and transport losses
- Non-existence of marketing network and infrastructure facility for quinoa
- Lack of national policy
- Lack of credit and investment
- Non-availability of scientific resources for testing, valuation and post-harvest management of quinoa

The availability of information has been always a major constraint in the promotion of quinoa crop. Improving the availability of information on quinoa has been one of the most important areas demanding our immediate attention. At the formal level, individual studies on these crops need to be supported to ensure their publication. At local level, there has been a need to gather and document information which has been maintained within farming communities. The recognition of the value of this by researchers and scientists can often act as a powerful stimulus to improve a community's own valuation of the knowledge (Singh *et al.,* 2008). A spectacular wide strategy has to be developed for quinoa for the benefit of mankind. But for the same protocol for increasing use of quinoa for food security involves overcoming many constraints and obstacles, from genetic through management, cultural acceptability and marketing to policy and decision-makers in the government (Padulosi *et al.,* 2013). There are very good examples for the development of an indigenous crop within its local community. Its provides direct benefits to community through food and often income security and increases the purchasing power (Mayes *et al*., 2011).

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(*Received :* January 2021 *Accepted :* February 2021)