

Review Articles

An Andean Ancient Crop, *Chenopodium quinoa* Willd.: A Review

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Abstract

Chenopodium quinoa Willd., is the oldest pseudocereal native from the Andean Region from 20° N in Columbia to 40°S in Chile, it grows from sea level to an altitude of 3 800 m, adapted to several agroclimates and abiotic stress. Quinoa is an annual plant that reaches a height of 0.2 to 3.0 m, it can display a variety of colours from the leaves and inflorescences. Quinoa seeds present a rich source of a variety of minerals, vitamins and higher contents of most essential amino acids, especially lysine which reveals its potential for a valuable ingredient in the preparation of highly nutritious food and also its nutraceutical properties. The high genetic variability and premises properties of quinoa make it potential to be grown worldwide, even it has been declared “The International Year of the Quinoa” (IYQ) by the United Nations in the year 2013.

Keywords: biodiversity; conservation; nutrition; pseudocereal.

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) belongs to the group of crops known as pseudocereals (Cusack, 1984; Kozoil, 1993) and to the Chenopodiaceae family. Quinoa is one of the oldest crops in the Andean Region, with approximately 7 000 years of cultivation, and great cultures such as the Incas and Tiahuanacu have participated in its domestication and conservation (Jacobsen, 2003). Even the sporadic failure of green revolution in the Andes and enormous destruction of other crops by droughts, native crops like quinoa showed much less reduction in the yields in severe conditions (Cusack, 1984). Quinoa was first botanically described in 1778 as a species native to South America, whose centre of origin is in the Andean of Bolivia and Peru (Cárdenas, 1944). It can be found at latitudes from 20°N in Columbia to 40°S in Chile, and from sea level to an altitude of 3 800 m (Bhargava et al., 2006). Recently, it has been introduced in Europe, North America, Asia and Africa (FAO, 2011). The year 2013 has been declared “The International Year of the Quinoa” (IYQ) by the United Nations. This crop is a natural food resource with high nutritive value and is becoming a high quality food for health and food security, for present and future human generations. The aim of this paper is to review the existing literature and explore the approaching of this crop for agricultural as well as several purposes.

Agronomy and potential adaptability of quinoa

Quinoa is an annual plant, usually herbaceous dicot that reaches a height of 0.2 to 3.0 m. Plants can display a variety of colours ranging from green through to red and

purple with many intermediate colours in between (Tapia, 1990; Mujica, 1992). The leaves are polymorphic; the basal leaves are large and can be rhomboid or triangular, while the upper leaves generally around the panicle are lancelets. Leaf colour ranges from green to red, through yellow and violet. The leaves are dentate, with up to 43 teeth on their margins, and they contain granules on their surface (Tapia, 1990). The inflorescence is racemose; the flowers are very small and dense, which makes emasculation difficult. The flowers remain open for a period ranging from 5 to 7 days (Mujica, 1992). The fruit is an achene, comprising several layers, perigonium, pericarp and episperm (Bhargava et al., 2007), from outwards to inside, and may be conical, cylindrical or ellipsoidal; saponins are concentrated in the pericarp. Seed size and colour are variable (Mujica, 1992). Black is dominant over red and yellow, which in turn are dominant over the white seed colour (Bhargava et al., 2007). In relation to its taxonomic classification, quinoa is a species that is classified in the division Magonoliophyta, class Magnoliopsida, subclass Caryophyllidae, order Caryophyllales, family Chenopodiaceae, genus *Chenopodium*, section *Chenopodia* and subsection *Cellulata* (Wilson, 1980). The genus *Chenopodium* is the largest in the family Chenopodiaceae and has a worldwide distribution, with about 250 species (Giusti, 1970).

Quinoa is well adapted to different climates, the crop can grow at relative humidity from 40% to 88%, and temperatures between 15 °C to 20 °C are ideal for its cultivation. Quinoa can resist temperatures from -4 °C to 38 °C. It is a plant showing a remarkable tolerance to abiotic stresses; in Chile, quinoa populations display a high degree of genetic distancing, and variable tolerance to salinity

(Ruiz, 2011). Effect of drought stress in quinoa was studied and show clear adaptation response even in the phenological development (Bois et al., 2006; Geerts et al., 2008). Bolivia's Southern Altiplano is considered the main geographic area where the crop is grown and produces a good percentage of the international demand for the crop. In the Southern Altiplano the mechanical agricultural system (95%) is replacing the traditional system (5%). In the traditional system, the soil is prepared with man-power using a tool called a Taquiza, Liukana, or Tankana to totally or partially remove the surface soil, depending on the production area. Sowing can be done in rows, groups, mixed, broadcast or by transplanting; row spacing of 25–50 cm is preferable since it allows easy hoeing. A level, well-drained seedbed is most suited for quinoa cultivation. Seeds should be sown 1–2 cm deep in a fine structured, moist seed bed (Jacobsen, 2003). Mechanical sowing is carried out by at least 70% of families and is performed with the Satiri drill. The opening of the furrowers can be adjusted to a distance between 0.8 to 1 m, and the seed is deposited in the furrows by impact, also at a distance of 0.8 to 1 m (Aroni, 2005). During the vegetative period, the quinoa crop is affected by a wide range of insects, of which around 17 species have been identified; they can cause several diseases. Among the main diseases is mildew, damping off, blight, mosaic. Viruses are known to infect the plant, but reports of significant damage are not available so far. Among the most economically important pests are the quinoa moths (*Eurysacca melanocampta* Meyrick) and the ticona complex (*Copitarsia turbata*, *Feltia* sp. *Heliothis titicaquensis*, *Spodoptera* sp.) (Saravia and Quispe, 2005). Losses caused by these pests can range from 5 to 67%, with an average of 33.37% in the Southern Altiplano and 6 to 45% in the Central Altiplano, with an average of 21.31% (FAO, 2011). Quinoa was successfully introduced and experimentally grown in typical agro-climatic conditions of South-Eastern Europe, giving a seed yield of 1.721 t ha⁻¹ of remarkable quality (Stikic, 2012). An evaluation of development and yielding potential of quinoa under European conditions is reported by Gesinsky (2008) who describe the clustering of countries using seven cultivars by the establishment of a test regarding temperature, rainfall, sun exposure as well as quinoa characteristics (vegetation period length, seed yield, green matter yield, seed diameter, reproduction effort ratio of the seed weight to the vegetative parts of the plant) from where high values of sun exposure and moderate rainfall stimulate yielding of *Chenopodium quinoa*.

The cultivar RU-5-PQCIP was the most favorable in Sweden. In Bydgoszcz (Poland) and Copenhagen (Denmark) most of the cultivars performed correctly, but the best cultivar was E-DK-4-PQCIP. Under the conditions of Italy and Greece a very high seed yield and high yield of green matter was reported. Jacobsen (2003) explored the

potential of quinoa worldwide describing the beginning of *Q. quinoa* in Europe, the countries with better yield, even the first European variety.

Nutritional value

The benefits of quinoa are due to its high nutritional value. Its grain is a rich source of a wide range of minerals, vitamins, oil containing large amounts of linoleate, and natural antioxidants (Koziol, 1992; Repo Carrasco et al., 2003) and high quality protein containing abundant amounts of sulphur-rich amino acids (Koziol, 1992). Quinoa leaves contain a high amount of ash (3.3%), fibre (1.9%), nitrates (0.4%), vitamin E (2.9 mg a-TE/100 g) and Na (289 mg/100 g), vitamin C (1.2–2.3g/kg) and 27–30g/kg of proteins (Bhargava et al., 2006). The total amount of phenolic acids varied from 16.8 to 59.7 mg/100 g and the proportion of soluble phenolic acids varied from 7% to 61%; which was low compared with common cereals like wheat and rye, but was similar to levels found in oat, barley, corn and rice (Repo Carrasco et al., 2010). Seed quality was remarkably good, with protein content ranging from 15.16% to 17.41% on a dry weight basis; amino acid and mineral composition (higher contents of most essential amino acids, especially lysine, than wheat flour) revealed the potential of quinoa seeds as a valuable ingredient in the preparation of highly nutritious foods (Stikic et al. 2012). Quinoa seed carbohydrates contain between 58 and 68% starch and 5% sugar, making it an ideal source of energy that is slowly released into the body owing to its high fibre content (FAO, 2011). They are rich in proteins and free essential amino acids, starch, minerals, ecdysteroid content and oils, but also contain low amounts of several vitamins and antioxidants (Kumpun et al., 2011).

Use of quinoa

The seed is used to make different food products including breads, biscuits, cookies, crepes, muffins, pancakes and tortillas. More recently, attention has been given to quinoa for people with celiac disease (allergy to gluten), as an alternative to the cereals wheat, rye and barley, which all contain gluten (Jacobsen, 2003). The seeds of this pseudocereal have been traditionally consumed as food by the native population of the Andes region and also used for animal feed (Bhargava et al., 2006). Until 2009, the export of this crop was approximately 15 000 MT and of this amount 95.3% originated from Bolivia, 2.7% from Peru and 2% from Ecuador (FAO, 2011). So far little information is available concerning the nutraceutical potential of the green parts of *C. quinoa*.

A high content of phenolic with well documented antioxidant activity, which includes free radical scavenging, reducing power, metal chelation, lipid protection against oxidation and LOX inhibition, confirms the strong nutraceutical potential of *C. quinoa*, relevant not only

to inhibit cancer proliferation but also to inflammatory processes (Hirose et al., 2010; Gawlik-Dziki et al., 2013). In particular, pseudocereal leaves, till now treated as worthless waste, are edible and may be consumed in salad, and also used as valuable supplement for functional food (Gawlik-Dziki et al., 2009). Few reports exist on the use of quinoa saponins against agricultural pests. Particularly, against fungi, the total saponin fraction of *C. quinoa* was found to slightly inhibit the growth of *Candida albicans* and it has recently been reported that the biological activity of quinoa saponins can be increased if they are treated with alkali (Woldemichael and Wink, 2001; Stuardo and San Martin, 2008). According to traditional medicine, all parts of quinoa are uses with specific instructions against several diseases such as anginas, cystitis, anthrax, herpes and other ailments as mentioned by Zalles and De Lucca (2006). Inclusion of using quinoa in tourism development programs that include agriculture as a component (agro-tourism, agro-ecotourism) are attractive alternatives for small growing areas and the promotion and conservation of less commercial ecotypes (FAO, 2011)

Genetic Diversity and Breeding Approach

Genetic diversity and reproductive biology knowledge is an effective way to enhance efficiency breeding program. Rojas et al. (2000) estimated genetic variability among Bolivian quinoa germplasm; there was much variation in phenolic variables, this broad variability is promising from the viewpoint of genetic improvement to cope with abiotic problems such as frost and drought, the two factors that affect most adversely crop production. Quinoa is an allotetraploid ($2n = 4x = 36$), and thus exhibits disomic inheritance for most qualitative traits (Ward, 1998; Maughan et al., 2004). The main genetic diversity centres are identified as the centre of Peru (Huancayo, Ayacucho, Cajamarca) that keeps selective germplasm in Experimental Stations of the National Institute of Agricultural Research (INIA) – in Illpa (Puno), Kayra and Andenes (Cusco), Canaan (Ayacucho), Mantaro and Santa Ana (Huancayo) and Baños del Inca (Cajamarca). The following universities also maintain quinoa germplasm: La Molina Agrarian University in Lima, National University of the Centre in Junín, National University of San Cristóbal de Huamanga in Ayacucho, National University of San Antonio Abad in Cusco, and National University of the Altiplano in Puno. In Bolivia, The Toralapa Centre of the National Institute of Agricultural and Forestry Innovation – INIAF, The Choquenaira Experimental Station of the Universidad Mayor de San Andrés – UMSA, The Biotechnology and Phytogenetic Resources Research Centre (CIBREF) of the Technical University of Oruro (UTO), The Tiahuanacu Academic Unit of the Bolivian Catholic University – UCB, The Kallutaca Experimental Centre of Public University El Alto – UPEA, The Centre of Comunal

Research and Promotion – CIPROCOM. Ecuadorian Mountain range, the Argentine Northeast, the South of Chile and of Colombia (Grass, Nariño and Cudinamarca). In Ecuador, there is only the Santa Catalina Experimental Station of the National Institute of Agricultural Research – INIAP, whereas in Colombia, there is the Obonuco-Nariño Experimental Station and at the National University of Bogotá. Meanwhile Chile has a gene bank at the Institute of Plant Production and Health at the Austral University of Chile (Jacobsen, 2003; FAO, 2011). In countries such as India, the National Botanical Research Institute, Lucknow, has initiated an extensive program, a coordinated effort of various departments like Plant Breeding and Genetics, Plant Pathology, Lipid Chemistry, Experimental Taxonomy, Biomass Biology, etc.

Up to now, only a few researchers have reported the development and use of molecular markers in quinoa. Wilson (1988) used data of alozymes in quinoa to confirm the genetic difference between ecotypes of the plateau and valleys. Maughan et al. (2004) made a genetic map of quinoa. Ruas et al. (1999) used RAPD markers to detect the degree of polymorphism between cultivated and wild species of quinoa. In order to establish genotypic differences between quinoas (*Chenopodium quinoa*) from the North and the South of Chile, studies of characterization of quinoa germplasm have been developed to create a map of microsatellite markers (Mason et al., 2005). Bhargava et al. (2007) made evaluation of seed yield, morphological variability and nutritional quality of 27 germplasm lines of *Chenopodium quinoa* and 2 lines of *C. berlandieri* subsp. *Nuttalliae*, carried out in subtropical North India. Rodriguez and Isla (2009) used AFLP to compare and analyze genetic and morphologic diversity among quinoa accessions) of the South of Chile and highland accessions.

CONCLUSION

Considering both the conditions under which quinoa is cultivated and its genetic variability, the plant has a remarkable adaptability to different agro-ecological zones. This adaptability is of great importance for the diversification of future agricultural systems; however there is an urgent need to strengthen the breeding programs in quinoa (conventional as well as biotechnological) for its genetic improvement and conservation. The high nutritional quality and multiple uses in food products make quinoa ideal also for utilisation by the food industry. Other potential uses are the medicinal and nutraceutical due its high phenolic acid content. To promote this promising crop, even the United Nations proclaimed “Quinoa 2013 International Year, a future sown thousands of years ago”. The aim of this project is to disseminate knowledge about quinoa worldwide, so as to help reduce

poverty by half by the end of 2015 (within Millennium Development Goals). Management strategies of quinoa cultivation among the farmers as well as the consumers, proper marketing and efficient post-harvest technologies. Quinoa has the potential to become an important industrial and food crop of the 21st century.

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