# Quinoa: An ancient crop to contribute to world food security

**July 2011**

Regional Office for
Latin America and the Caribbean

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## Preface

The technical report ***"Quinoa, an ancient crop to contribute to world food security"*** produced by PROINPA is an updated and detailed compilation of the nutritional benefits and agricultural versatility of quinoa; the expansion of the crop to other continents and showing that it is a crop with high potential to contribute to food security in various Regions worldwide, especially in those countries where the population does not have access to protein sources or where production conditions are limited by low humidity, reduced availability of inputs, and aridity.

This report was submitted by the Multinational State of Bolivia to the 37th FAO Conference in support of the declaration of the "International Year of quinoa", which was approved, declaring 2013 the International Year of quinoa.

Quinoa is the only plant food that contains all the essential amino acids, trace elements and vitamins and contains no gluten. Essential amino acids are found in the nucleus of the grain, unlike other cereals, like rice or wheat, in which they are located in their exosperm or hull.

Furthermore, the crop has a remarkable adaptability to different agro-ecological regions. It can grow at relative humidity from 40% to 88%, and withstands temperatures from -4 ° C to 38 ° C. It is a highly water efficient plant, is tolerant and resistant to lack of soil moisture, and produces acceptable yields with rainfall of 100 to 200 mm.

There are more than three thousand varieties or ecotypes of quinoa both cultivated and wild which can be grouped in five basic categories according to the altitudinal gradient: ecotypes from sea level, the valleys, the Yungas, the Salt flats and the Altiplano (high plain).

While the main producers are Bolivia, Peru and the United States, quinoa production is expanding to other continents and it is currently being cultivated in several countries in Europe and Asia with good yields. This report contributes to improving knowledge and dissemination of this ancient crop, which has a significant strategic value for the food and nutritional security of humanity.

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Multidisciplinary Team Coordinator for South America

**Resolution**

**International Year of Quinoa 63**

63 C 2011/INF/18 Rev.1; C 2011/LIM/17; C 2011/LIM/20; C 2011/I/PV/4; C 2011/I/PV/5; C 2011/PV/11.

137. The Conference reviewed the proposal made by the Government of Bolivia to declare 2013 the International Year of Quinoa.

138. The Conference noted the exceptional nutritional qualities of Quinoa, its adaptability to various growing conditions and potentially significant contribution to the fight against hunger and malnutrition.

139. Many delegations supported holding the International Year of Quinoa in 2013.

140. Questions were raised based on whether the current proposal met the agreed United Nations General Assembly (UNGA) criteria. The Conference requested that this proposal be forwarded to the next UNGA for consideration and adopted the following Resolution:.

**Resolution 15/2011**
***The International Year of Quinoa***
**THE CONFERENCE,**
**Noting** that quinoa is a natural food high in nutritional value; 30 C 2011/REP

**Recognizing** that Andean indigenous peoples, through their traditional knowledge and practices of living well in harmony with mother earth and nature, have maintained, controlled, protected and preserved quinoa in its natural state, including its many varieties and landraces, as food for present and future generations;

**Affirming** the need to focus world attention on the role that quinoa biodiversity plays, owing to the nutritional value of quinoa, in providing food security and nutrition, the eradication of poverty in support of the achievement of the internationally agreed development goals, including the Millennium Development Goals, and the outcome document of the High-Level Plenary Meeting on the Millennium Development Goals;

**Recalling** the Rome Declaration on World Food Security and the World Food Summit Plan of Action (13-17 November 1996), the Declaration of the World Food Summit: five years later (10-13 June 2002), and the Declaration of the World Summit on Food Security (16-18 November 2009);

**Affirming** the need to heighten public awareness of the nutritional, economic, environmental, and cultural properties of quinoa:

1) **Requests** the Director-General to transmit this Resolution to the Secretary-General of the United Nations with a view to having the General Assembly of the United Nations consider at its next session declaring the year 2013 as to the International Year of Quinoa.

2) **Further requests** the Director-General to inform future sessions of the FAO Council, as appropriate, and the Secretary-General of the United Nations of arrangements made in securing extra-budgetary funding for the International Year of Quinoa and, subsequently, of the results of the Year once concluded.

(Adopted on 2 July 2011)

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## Executive summary

The Andean Region, the cradle of great civilizations such as the Inca and Tiahuanaco is considered the centre of origin of many native species such as quinoa (*Chenopodium quinoa* Willd), which for thousands of years was the main food of the ancient cultures of the Andean and is distributed in different agro-ecological zones within the Region. Currently, quinoa is in a process of expansion because it has great potential to improve the living conditions of people in the Andean and the modern world.

Quinoa is a grain that has outstanding intrinsic characteristics, such as:

- Its broad **genetic variability**. Its gene pool is extremely strategic for developing superior varieties (precocity, grain size and colour, resistance to biotic and abiotic factors, grain yield and byproducts);
- Its **adaptability** to adverse climate and soil conditions. Crops can be produced from sea level to 4000 meters (Altiplano, salt lakes, Puna (high grasslands), valleys,and sea level) in areas where other crops can not grow;
- Its **nutritional quality**, represented by its essential amino acid composition in both quality and quantity, making it a functional and ideal food for the body;
- The diversity of **methods of use**: traditional, nontraditional and industrial innovations; and
- Its low production cost because the crop requires little in the way of inputs and labour.

Faced with the global need to identify crops with potential to produce quality food, quinoa has a high potential both for its nutritional benefits and its agricultural versatility to contribute to food security in various Regions of the planet, especially in countries which are limited in food production or where the population has no access to protein sources.

Quinoa is remarkably adaptable to different agro-ecological zones. It adapts to climates from desert to hot, dry climates, can grow at relative humidities from 40% to 88%, and withstands temperatures from -4 ° C to 38 ° C. It is a highly water efficient plant, is tolerant and resistant to lack of soil moisture, and produces acceptable yields with rainfall of 100 to 200 mm.

Quinoa cultivation is expanding, the main producers being Bolivia, Peru, United States, Ecuador and Canada. Quinoa is also cultivated in England, Sweden, Denmark, the Netherlands, Italy and France. Recently France has reported an area of 200 ha with yields of 1,080 kg / ha and Kenya has shown high seed yields (4 t / ha). In the Himalayas and the plains of Northern India, the crops can develop successful and with high yields . In tropical areas such as the savannas of Brazil there has been experimental quinoa cultivation since 1987 reportedly obtaining higher yields than in the Andean area. Quinoa is highly attractive in different Regions of the world for its extraordinary adaptability to extreme ecological conditions.

In recent years (2009) production in the Andean Region was about 70,000 t with almost 40,000 t produced by Peru, 28,000 t by Bolivia and 746 t by Ecuador. Undoubtedly the main quinoa producing countries in the Andean Region and the world are Peru and Bolivia; until 2008 the production of both countries accounted for 90% of world quinoa production. Following them are the United States, Ecuador and Canada with about 10% of global production volumes.

Bolivia is the largest exporter of quinoa in the world followed by Peru and Ecuador. In 2009 Bolivia exported a value of over US $ 43 million (Bolivian Institute of Foreign Trade - IBCE, 2010). The major importers of Bolivian quinoa grain are: United States (45%), France (16%), Netherlands (13%), Germany, Canada, Israel, Brazil and the United Kingdom. In 2007, Peru exported volumes somewhat greater than 400 MT of quinoa grain with values equivalent to US $ 552,000. In 2008 Ecuador showed similar export levels: 304 MT worth US $ 557,000. Consumers in North America and Europe have a tendency to greater interest in health care, environment and social equity. The niche markets for organic and fair trade products therefore offer interesting alternatives and better producer prices, and so the price of organic quinoa in 2010 was US $ 3.1 / kg, well above the soybean (US $ 0.4 / kg) and wheat (IBCE 2010).

In 1996, quinoa was classified by FAO as one of humanity's most promising crops, not only for its beneficial properties and its many uses, but also considering it as an alternative to solve the serious problems of human nutrition. NASA also included it within the system CELSS (Controlled Ecological Life Support System) to equip its rockets in long-duration space travel, being a food of excellent nutritional composition, as an alternative to solve the problems of inadequate protein intake. There are several products derived from quinoa, such as puffs, flour, pastas, flakes, granola, energy bars, etc. However other products which are more developed or whose production require the use of advanced technologies are also in the process of being exploited, such as the extraction of quinoa oil, starch, saponin, colourings from the leaves and seeds, protein concentrates, etc.. These products are considered to be the economic potential of quinoa because they make use of not only its nutritional but also its physicochemical characteristics, reaching beyond the food industry and offering products to the chemical, cosmetic and pharmaceutical industries.

# CHAPTER 1

## General Context

### 1.1. Centre of origin and diversity

Quinoa (*Chenopodium quinoa* Willd.) was first botanically described by Willdenow in 1778 as a species native to South America, whose centre of origin, according to Buskasov, is in the Andean of Bolivia and Peru (Cárdenas, 1944 ). This was corroborated by Gandarillas (1979b), who indicated that its geographical range is quite wide, not only because of its social and economic importance, but because this is where the greatest diversity of ecotypes are found, both technically cultivated and in the wild.

According to Vavilov, the Andean Region corresponds to one of the great centres of origin of cultivated species (Lescano, 1994), and within it there are different subcentres. According to Lescano, in the case of quinoa there are five main groups categorized according to the agroecological conditions where they grow: Altiplano, salt flats, Yungas, valleys, and sea level, and which present different botanical, agronomic and adaptive characteristics.

In the particular case of Bolivia, studies of the genetic variability of the quinoa germplasm collection, (Rojas , 2003) have identified six sub-centers of diversity, four of them located in the Altiplano of La Paz, Oruro and Potosi which harbour the largest genetic diversity, and two in the valleys of Cochabamba, Chuquisaca and Potosi.

### 1.2. Archaeological and historical background

Heisser and Nelson (1974) indicate archaeological finds in Peru and Argentina around the beginning of the Christian era, while Bollaerd and Latcham, cited by Cardenas (1944) also found quinoa seeds in Indigenous graves of Tarapaca, Calama, Tiltel and Quillagua, demonstrating that this crop has been cultivated since ancient times. According to Jacobsen (2003) quinoa is one of the oldest crops in the Andean Region, with approximately 7000 years of cultivation, and great cultures such as the Incas and Tiahuanacu have participated in its domestication and conservation.

Quinoa was widely cultivated in the Andean Region by pre-Columbian cultures and its grains have been used in the diet of inhabitants of the valleys, and in drier areas (350 mm of precipitation) with higher altitudes (above 3500 m) and colder temperatures (average 12 º C) such as the Altiplano. Despite being a fully domesticated species, the fruits still contain saponin, so its removal is necessary before they can be consumed (Mujica, 1992; Heisser and Nelson, 1974). Marginalization and replacement of this crop began with the Spanish conquest and the introduction of cereals such as barley and wheat (Mujica, 1992; Jacobsen and Stolen, 1993). In this regard, Risi (1997) indicates that the crop was never lost among the Andean people, but went unnoticed among the urban population of the Region for mainly economic and social reasons.

Risi (1997) notes that the economic crisis in the Andean countries during the 80's, established new patterns of economic development which differed from traditional ones, as they contemplated the development of non-traditional export systems, taking into account the opening of new markets in Europe and the United States, especially for food products such as quinoa. The welfare achieved by developed countries has led to the expansion of their food consumer markets in the search for new foods, often linked to ancient cultures. This situation has meant that quinoa has been transformed from a subsistence crop into a product with export potential.

## 1.3. Geographic distribution

Quinoa can be seen as an oligocentric species with a broad center of origin and multiple diversification. Shores of Lake Titicaca being considered as the area of greatest diversity and genetic variation (Mujica, 1992).

According to Lescano (1994) quinoa is distributed throughout the entire Andean Region, from Colombia (Pasto) to northern Argentina (Jujuy and Salta) and Chile (Antofagasta), where a group of quinoas have been found at sea level at the Bío Bío Region. Barriga *et al.* (1994) also refer to quinoa collected in the Ninth and Tenth Regions of Chile.

According to Rojas (1998) the geographical distribution of quinoa in the Region extends from latitude 5 degrees North in Southern Colombia, to latitude 43 ° South in the Xth Region of Chile, and its altitudinal distribution ranges from sea level in Chile to 4000 m in the Altiplano of Peru and Bolivia. Thus, existing quinoas of the coast, valleys, interandean valleys, Puna and Altiplano.

The following is a summary of quinoa distribution, according to the countries of the Region and their traditional areas of production (Rojas *et al*., 2010):

- In **Colombia** in the Department of Nariño, in the towns of Ipiales, Puesres, Contadero, Cordova, San Juan, Mocondino and Pasto.
- In **Ecuador** in the areas of Carchi, Imbabura, Pichincha, Cotopaxi, Chimborazo, Loja, Latacunga, Ambato and Cuenca.
- In **Peru** the areas of Cajamarca, Callejón de Huayllas, Valle del Mantaro, Andahuayllas, Cuzco and Puno (Altiplano) are highlighted.
- In **Bolivia** in the Altiplano of La Paz, Oruro and Potosi and the valleys of Cochabamba, Chuquisaca, Potosi and Tarija.
- In **Chile**, the Chilean Altiplano (Isluga and Iquique) and Concepción. There are also reports of quinoa grown in the IXth and Xth Regions (Barriga et al., 1994).
- In **Argentina** it is grown in isolation in Jujuy and Salta. Its cultivation was also extended to the Calchaquíes valleys of Tucumán (Gallardo and Gonzalez, 1992).

The geographic distribution of world quinoa production is shown in Figure 1, where it can be seen that countries with the greatest production are Bolivia, Peru and Ecuador. However, as a result of more than twenty years of work in potential countries of Europe, Asia, Africa, Australia, North America and the Andean Region, quinoa production is in a process of expansion into different geographic areas of the planet due to its extraordinary adaptability.


**Figure 1.** Geographic distribution of world quinoa production

## 1.4. Potential contribution of Quinoa to Food security and sovereignty

The situation of food production and distribution in the world presents challenges of great magnitude to the four pillars of food security: availability, access, consumption and biological utilization.

In this context quinoa constitutes a strategic crop with potential to contribute to food security and sovereignty due to: **nutritional quality, genetic variability, adaptability** to adverse climate and soil conditions, and low production cost.

The cultivation of quinoa provides an alternative for countries with limited food production, which are therefore forced to import or receive food aid.

In chapters three, four and five information is provided on the nutritional benefits and agricultural versatility of quinoa, respectively, showing that quinoa is a crop with high potential to contribute to food security in various Regions worldwide, especially in countries where the population has no access to protein sources or where production conditions are limited by low humidity, reduced availability of inputs and aridity.

## 1.5. Historical and cultural importance

Latcham, cited by Cardenas (1944), argues that quinoa replaced corn in the entire Andean Region from Colombia to the south of Chiloe Island, having also acclimatized in many parts of the coast. Cardenas believed that in Colombia quinoa was introduced too late to address the lack of corn in some cold areas, and its undoubtable that during the Inca Empire quinoa was widespread in Ecuador, Peru, Bolivia, Chile and northwest Argentina, given its economic importance, since apart from their protein rich seeds, its leaves were also used in salads.

However, genetic erosion has been intense since the discovery of America. The botanist O.F. Cook mentions that in the sixteenth century there were more species domesticated in the Andean Region than in Asia or Africa (Tapia, 1992), mainly due to the replacement of local crops by others brought from Europe. This erosion was emphasized by social changes and people's attitudes about foreign crops, where a social prestige was created which led to Andean crops being undervalued (Lescano, 1989). The survival of Andean crops was made possible by the peasant communities that inhabit the area, who based on their traditions and ancestral knowledge about the management and use of these species have managed to prevent their loss.

# CHAPTER 2

## Nutritional properties

The unique benefits of quinoa are related to its high nutritional value. The protein content of quinoa ranges between 13.81 and 21.9% depending on the variety. Due to the high content of essential amino acids in its protein, quinoa is considered the only plant food that provides all essential amino acids, which are extremely close to human nutrition standards established by the FAO. In this regard Risi (1993) notes that the balance of essential amino acids in quinoa protein is superior to wheat, barley and soybeans, comparing favorably with milk protein. In Table 1 quinoas nutritional composition is compared with that of meat, egg, cheese and milk.

**Table 1.** Nutritional composition of quinoa compared with staple foods (%)

| Components (%) | Quinoa | Meat | Eggs | Cheese | Cows milk | Human Milk |
|---|---|---|---|---|---|---|
| Proteins | 13.00 | 30.00 | 14.00 | 18.00 | 3.50 | 1.80 |
| Fats | 6.10 | 50,00 | 3,20 | | 3.50 | 3.50 |
| Carbohydrates | 71.00 | | | | | |
| Sugar | | | | | 4.70 | 7.50 |
| Iron | 5.20 | 2,20 | 3,20 | | 2.50 | |
| Calories per 100 g | 350 | 431 | 200 | 24 | 60 | 80 |

Source: Agrifood report, 2009 MDRT-BOLIVIA

## 2.1. Composition and functional value

For some populations of the world, including high quality protein in the diet is a concern, especially for those who rarely eat animal protein and need to obtain protein from cereals, legumes and other grains. Even when the energy intake of these foods is adequate, inadequate levels of essential amino acids (EAA) can increase the prevalence of malnutrition.

A key feature of quinoa is that the grain, leaves and inflorescences are all sources of high quality protein. The nutritional quality of the grain is important due to its protein content and quality. Quinoa is rich in lysine and the sulfur amino acids, while cereal proteins are deficient in these amino acids.

However, despite its good nutrient content, research concludes that the amino acids in the raw unwashed flour are not fully available because they contain substances that interfere with the biological utilization of nutrients. These substances are called saponin glycosides.

Quinoa has a high percentage of total dietary fibre (TDF), which makes it an ideal food to detoxify the body, eliminating toxins and waste products that may harm the body. Quinoa produces a feeling of fullness. Cereals in general and quinoa in particular, have the ability to absorb water and stay longer in the stomach.

### 2.1.1. Proteins

General comparison is made between the nutrient composition of quinoa, and wheat, rice and corn (traditionally referred to in the literature as the golden grains) it can be seen that the mean values reported for quinoa are superior to those of the other three grains with regards to protein, fat and ash content (Rojas et al., 2010a).

The literature on human nutrition indicates that only four amino acids are likely to limit the quality of mixed human diets. These amino acids are lysine, methionine, threonine and tryptophan. Thus by comparing the essential amino acid content of quinoa with wheat and rice, quinoas great nutritional advantage can be appreciated: for example, quinoa´s content of the amino acid lysine is 5.6 grams of amino acid / 16 grams of nitrogen compared with rice which has 3.2 g and wheat which has 2.8g (Repo-Carrasco, 1998).

In some areas farmers remove the quinoas bitterness by subjecting the grain to heat and then washing it. This process of roasting with dry heat is used by some companies to remove the hull which contain saponin (Tapia, 1997). After toasting the quinoa grains acquire a brown colour caused by the presence of reducing sugars that produce a Maillard reaction. The lysine in this form is not biologically useful (it loses its nutritional value).

Between 16 and 20% of the quinoa seed´s weight corresponds to proteins of high biological value, which contain all the amino acids, including the essential ones, ie, those that the body can not synthesize itself and therefore must be supplied in the diet. The amino acid content of the quinoa grain´s protein meets the amino acid requirements recommended for preschool children, school children and adults (FAO / WHO / UNU, 1985). However, the importance of quinoa proteins is their quality. Quinoa proteins are mainly albumin and globulin types. They have a balanced composition of essential amino acids similar to the amino acid composition of milk protein casein. It has also been found that quinoa leaves have a high content of quality proteins. In addition, the leaves are also rich in vitamins and minerals, especially calcium, phosphorus and iron.

100 grams of quinoa contains nearly fivefold lysine, more than double isoleucine, methionine, phenylalanine, threonine, valine, and much larger amounts of leucine (all essential amino acids along with tryptophan) than 100 grams of wheat. In addition it also exceeds wheat, in some cases by the triple, in the amounts of histidine, arginine, alanine and glycine as well as containing amino acids not present in wheat such as proline, aspartic acid, glutamic acid, cysteine, serine and tyrosine (all nonessential amino acids).

Quinoas exceptional amino acid richness confers it with very interesting therapeutic properties. This is because the bioavailability of lysine in quinoa, the most abundant essential amino acid in its seeds, is very high while in wheat, rice, oats, millet and sesame it is significantly lower. This amino acid enhances immune function by aiding in the formation of antibodies, promotes gastric function, assists in cell repair, is involved in the metabolism of fatty acids, helps calcium absorption and transport, and -together with vitamin C- even seems to slow or prevent cancer metastasis, to name just a few of its many therapeutic actions.

As for Isoleucine, leucine and valine, these amino acids participate together in the production of muscle energy, improve neuromuscular disorders, prevent liver damage and balance blood sugar levels, among other functions. Methionine is used by the liver to produce s-adenosine-methionine, a substance particularly effective in treating liver disease, depression, osteoarthritis, brain disorders, fibromyalgia and chronic fatigue, among other ailments. It also acts as a powerful detoxifying agent that significantly decreases the levels of heavy metals in the body and exerts a strong protection against free radicals.

Quinoa also contains interesting amounts of phenylalanine (a brain stimulant and the main element of the neurotransmitters that promotes alertness and relieves pain and depression, among other functions), threonine (involved in liver detoxification, participates in the formation of collagen and elastin, and facilitates the absorption of other nutrients) and tryptophan (immediate precursor of the neurotransmitter serotonin, for which it has been used successfully in cases of depression, stress, anxiety, insomnia and compulsive behavior).
With regard to "non essential" amino acids, quinoa contains more than triple the amount of triplehistidine in wheat, a substance which is essential for infants because the body can not synthesize it until adulthood so it is strongly recommended that children acquire it through their diet, especially during periods of growth. It also has a slightly anti-inflammatory action and participates in the immune system response.

Arginine, in turn, is also considered an almost essential amino acid in infancy, childhood and adolescence as it stimulates the production and release of growth hormone, as well as improving the activity of the thymus and T lymphocytes, participating in muscle growth and repair, and protecting and detoxifying the liver. Alanine is an energy source for the muscles, brain and nervous system and glycine acts as a calming neurotransmitter in the brain and as a regulator of motor function. In addition, the amino acid proline, that other grains like wheat do not contain, contributes to joint repair, is necessary for healing wounds and ulcers, appears to be effective in treating cases of impotence and frigidity, is a cardiovascular protector and is used together with lysine and vitamin C to prevent or limit cancer metastasis.

Other amino acids present in quinoa but uncommon in other cereals are aspartic acid (which improves liver function and is essential for the maintenance of the cardiovascular system), glutamic acid (involved in the production of energy for the brain and important phenomena such as learning, memory and neuronal plasticity), cysteine (which protects the liver by binding to heavy metals and facilitating their removal in addition to destroying free radicals and boosting the immune system), serine (potent natural moisturizer)and tyrosine (which has an important anti stress effect and plays a fundamental role in alleviating depression and anxiety, among other functions).

The protein digestibility or bioavailability (true digestibility) of quinoa´s amino acids varies depending on the variety and the treatment they are subjected to. Comparative studies (FAO / WHO, 1991) using the balance method in rats ranked the values of true digestibility of protein in three ranges: high digestibility from 93 to 100% for animal foods and soy protein isolate; intermediate digestibility values of 86 to 92% for polished rice, whole wheat, oatmeal and soy flour, and low digestibility of 70 to 85% for corn and different types of pulses including beans and lentils. According to this classification, quinoa grain is in third position, ie with low digestibility (Ayala et al., 2004).

In order to introduce the concept of genetic diversity in studies on the nutritional and agro-industrial value of quinoa, PROINPA has carried out various studies of the genetic wealth held by the Bolivian National Germplasm Bank of Andean Grains, analysing germplasm samples in order to quantify the genetic variation of these characteristics and on this basis promoting their use according to the intrinsic abilities of each genetic material. In the study of 555 quinoa accessions it was observed that 469 accessions have a protein content ranging from 12 to 16.9%, while there was a group of 42 accessions whose content ranged from 17 to 18.9%. This latter group constitutes an important source of genes to boost the development of high protein products.

### 2.1.2. Fats

It is important to emphasize the relatively high amount of oil in quinoa, a very understudied aspect of the crop, which makes it a potential source for oil extraction (Repo-Carrasco et al., 2001).

Studies carried out in Peru to determine the fatty acid content of quinoa found that the highest percentage of fatty acid in this oil is Omega 6 (linoleic acid), 50.24%, very similar to the values found in corn germ oil, which has a range of 45 to 65%.

Omega 9 (oleic acid) is second in quantity, accounting for 26.04% of quinoa oil. The valuesfound for Omega 3 (linolenic acid) are 4.77%, and palmitic acid accounted for 9.59%. Additionally a small proportion of fatty acids such as stearic acid and eicosapentaenoic acid were also found. The composition of these fatty acids is very similar to corn germ oil.

Wood *et al.* (1993) found that of quinoa´s total fatty acids 11% were saturated, being palmitic acid as the predominant acid. Linoleic, oleic and alpha-linolenic acids were the predominant unsaturated acids with concentrations of 52.3, 23.0 and 8.1% of total fatty acids, respectively. Quinoa oil also contains approximately 2% erucic acid. Other researchers (Przybylski et al., 1994) found that quinoa´s main fatty acid was linoleic acid (56%), followed by oleic acid (21.1%), palmitic acid (9.6%) and linolenic acid (6.7%). According to these authors, 11.5% of quinoa´s total fatty acids are saturated.

Quinoa helps reduce LDL (or bad cholesterol) in the body and raise HDL (good cholesterol) due to its omega 3 and omega 6 content.

In some cases, 82.71% of fatty acids in quinoa oil are unsaturated. In recent decades, unsaturated fatty acids have become known for their beneficial action in the body, by maintaining the fluidity of lipid membranes.

The study of 555 accessions of the Bolivian quinoa collection, found that the fat content ranged from 2.05 to 10.88% with an average of 6.39%. The upper range of these results is greater than the range of 1.8 to 9.3% reported by Bo (1991) and Moron (1999) cited by Jacoobsen and Sherwood (2002), who suggest that quinoa´s fat content is very valuable due to its high proportion of unsaturated fatty acids. These values from quinoa germplasm are expected in the extraction of fine vegetable oils for culinary and cosmetic uses (Rojas et al., 2010).

### 2.1.3. Carbohidrates

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 (Llorente JR, 2008).

Starch is the most significant carbohydrate in all grains, representing approximately 60 to 70% of dry matter. Quinoa starch content is 58.1 to 64.2% (Bruin, 1964). The starch in plants is in the form of granules. The granules of each species have a characteristic size and shape. The starch granules of quinoa have a diameter of 2 μm - smaller than those of common grains. Quinoa starch has been studied very little. It would be important to study its functional properties. Ahamed et al. (1998) mention that quinoa starch is highly freeze/thaw stable and is resistant to retrogradation. These starches could provide an interesting alternative to replace chemically modified starches (Repo-Carrasco et al., 2001).

Genetic variation of starch granule size in the Bolivian quinoa collection ranged from 1 to 28 μm, this variable can be used to make different mixtures with cereals and legumes, and establish the functional nature of quinoa (Rojas et al ., 2010a).

### 2.1.4. Minerals

If a comparison is made between wheat, corn, rice, barley, oats, rye, triticale, and quinoa, quinoa stands out for its high content of calcium, magnesium and zinc.

Quinoa is a food rich in:

- Calcium, which is easily absorbable by the body (containing more than four times that of corn, almost triple that of rice and much more than wheat), and quinoa can therefore help to prevent decalcification and osteoporosis. Calcium is responsible for many structural functions of hard and soft tissues of the body as well as the regulation of neuromuscular transmission of chemical and electrical stimuli, cell secretion and blood clotting. Thus calcium is an essential component of the diet. The recommended daily intake for calcium is 400 mg / day for children 6 to 12 months to 1300 mg / day for adults (FAO / WHO, 2000) and is covered with an average consumption of food from 800 to 1000 mg / day. Quinoa provides 114 to 228 mg / day, with a calculated average of 104 mg/100 g of edible portion. Ruales and Nair (1992) indicate that the calcium content of quinoa is between 46 to 340 mg/100 g of dry matter.

- Iron: It contains three times more than wheat and five times more than rice, while corn lacks this mineral completely.

- Potassium: it contains twice that of wheat, four times more than corn and eight times more than rice).

- Magnesium, also in much higher amounts than in the other three grains. An adult man of 70 kg contains about 20 to 28 g of magnesium and the recommended daily intake is about 300 to 350 mg / day for adults (National Research Council, 1989). Quinoa contains 270 mg/100 g of dry matter. Ruales and Nair (1992) present figures ranging from 170 to 230 mg/100 g of dry matter. Magnesium is a component and activator of many enzymes, especially those that convert energy-rich phosphates. It is also a stabilizer of nucleic acids and membranes.

- Phosphorus: The levels are similar to wheat but much higher than rice, and especially corn.

- Zinc: almost double the amount found in wheat and four times that of corn, while rice does not contain this mineral. The zinc content of an adult male weighing 70 kg is 2 to 4 g. Zinc acts on the synthesis and degradation of carbohydrates, lipids, proteins and nucleic acids. If the body can make use of 20% of the zinc available in food, recommended intakes are 8.3 mg / day (children under 1 year), 8.4 and 11.3 mg/ day (preschool and school children), 15.5 and 19.5 mg / day (adolescents) and 14 mg / day (adults) (FAO / WHO, 2000). Therefore, an intake between 6 and 20 mg / day is sufficient and in this sense, quinoa provides 4.8 mg/100 g of dry matter. However, these figures can vary from 2.1 to 6.1 mg / 100 g dry matter (Ruales and Nair, 1992).

- Manganese: only wheat exceeds quinoa in its manganese content, while rice has half as much and a corn only a quarter.

- Small amounts of copper and lithium (JR Llorente, 2008).

### 2.1.5. Vitamins

Table 2 shows the vitamin content of the quinoa grain. Vitamin A, which is important for vision, cell differentiation, embryonic development, immune response, taste, hearing, appetite and development, is present in the quinoa grain in the range of 0.12 to 0.53 mg/100 g dry matter (Oslo, 1997, cited by Ayala et al., 2004).

Vitamin E has antioxidant properties and prevents lipid peroxidation, thus contributing to maintaining the stability of cell membrane structures and protecting the nervous system, muscle and retina from oxidation. Daily needs are in the order of 2.7 mg / day and for children 7 to 12 months they are 10 mg / day of alpha-tocopherol or equivalents (FAO / WHO 2000, cited by Ayala et al., 2004). According to Table 2 quinoa reports a range of 4.60 to 5.90 mg of vitamin E/100 g dry matter.

**Table 2.** Vitamin content of the quinoa grain (mg/100 g dry matter)

| Vitaminas | Rango |
|---|---|
| Vitamin A (carotenes) | 0.12 – 0.53 |
| Vitamin E | 4.60 – 5.90 |
| Thiamine | 0.05 – 0.60 |
| Riboflavine | 0.20 – 0.46 |
| Niacin | 0.16 – 1.60 |
| Ascorbic acid | 0.00 – 8.50 |

Source: Ruales et al.,1992, cited by Ayala et al., 2004.

The inadequate intake of foods rich in thiamine or vitamin B1 (grains, vegetables, legumes, tubers, yeast, offal, milk, fish and eggs) in developing countries leads to vitamin deficiency known as beri-beri. The recommended daily intake of thiamine is 0.3 mg/1000 kcal for children aged 7 to 12 months and 1.2 mg / day for adults. Thiamine is distributed in the pericarp of the quinoa grain and according to Table 2, its content is in the order of 0.05 to 0.60 mg/100 g dry matter (FAO / WHO 2000, cited by Ayalaet al., 2004).

## 2.2. Nutraceutical and medicinal properties

It is noteworthy that quinoa contains dietary fibre, is gluten free and contains two phytoestrogen - daidzein and cenisteína - that help prevent osteoporosis and many of the organic and functional disorders caused by lack of estrogen during menopause, as well as favouring an adequate metabolic activity and proper blood circulation.

### 2.2.1. Dietry fibre

Fibre accounts for 6% of the grains total weight, and quinoa intake therefore promotes intestinal transit, regulates cholesterol, stimulates the development of beneficial bacterial flora and helps prevent colon cancer. It has a high percentage of total dietary fibre (TDF), which makes it an ideal food for helping to eliminate toxins and waste products that can damage the body. It therefore acts as a purifier of the body.

It produces a feeling of fullness. Grains in general, and quinoa in particular, have the ability to absorb water and stay longer in the stomach and in this way fullness is achieved with a low volume of cereal.

### 2.2.2. Gluten free

A team of researchers at King's College London have discovered that quinoa helps coeliacs to recuperate gluten tolerance. They found that if a coeliac leads a gluten-free diet http://www.celiacos.com/category/productos-sin-gluten/ which is also rich in quinoa, they can recover bowel function in much less time.

The results obtained so far by the research team were presented by the Spanish biochemist Victor Zeballos at the Third World Congress of Quinoa, held in Oruro, Bolivia.

The main objective of the study is to discover to what extent quinoa is beneficial for coeliacs, in what way its regular intake benefits the intestine and how it can be used to fight celiac disease.

So far, studies have found that regular consumption of quinoa improves the small intestine of coeliacs and returns their intestinal villi to normal, much faster than with a simple gluten-free diet.

It appears that in this respect the most important thing about quinoa is its low level of prolamins, but the analysis of other Andean grains has not been dismissed, while experts state that these results are not definitive and must be treated with caution.

### 2.2.3. Medicinal use

The use of Quinoa in traditional medicine is known since ancient times. In the communities of the Altiplano and valleys it is mentioned that Kallawaya (which in Aymara means carriers of medicinal herbs) healers make multiple uses of the quinoa grain, stems, and leaves for healing and even magical purposes. The modes of preparation and application vary for internal and external use. Its most frequent uses include treating abscesses, bleeding and dislocations.

According to traditional medicine, the quinoas stems and leaves cooked with oil, vinegar and pepper increase the blood. The leaves cooked with vinegar and used as a gargle or applied as a poultice to heal sore throats and anginas. A decoction of the leaves prepared with sugar and cinnamon purifies the stomach, dislodges phlegm and bile and removes nausea and heartburn. An infusion of the leaves is used to treat urinary tract infections or as a laxative.

The fresh leaves of quinoa 'chiwa', consumed either as a soup or dessert, are a remedy against scurvy and other illnesses or diseases caused by vitamin deficiency. It is a proven remedy against Anthrax, herpes, urticaria, 'llejti' and other skin conditions (Zalles and De Lucca, 2006). The quinoa grain can be used in different ways to combat liver disease, angina and cystitis. It is a dental analgesic and has both anti-inflammatory and healing properties, and poultices of black quinoa, combined with some other plants, are applied to heal broken bones. Its fruit contains a large amount of alkaline substances and is used as a remedy for sprains, fractures and dislocations, making a paste by mixing it with alcohol or brandy. It is also recommended as a refrigerant, a diuretic and to prevent colics. The specialization of quinoa is as an anti-blennorrhoeal remedy and in the treatment of tuberculosis.

A decoction or poultice made from the fruits is used medicinally to apply to wounds and bruises. The water from the cooked grain cures liver abscesses, internal secretions and catarrhal afflictions. According to Kallawaya healers it is a mild laxative, good for insomnia, combats dandruff and is a good hair tonic. Likewise, the cooking water from the cooked grain mixed with milk and almond oil is used to wash the ears where there is pain, noise and deafness (Pinto et al., 2010).

According to Zalles and De Lucca (2006), a good sudorific is produced by cooking five tablespoons of quinoa seeds in two bottles of water. The same decoction, sweetened with honey or molasses, is a proven remedy against bronchial disorders, colds, cough and inflammation of the tonsils.

The broth, soup, or warm grain of quinoa is a nutritive tonic, increases breast milk, is restorative and protects against tuberculosis. Quinoa soup with ullucu or chopped papalisa or quinoa chichi, immediately increases the milk supply of lactating women. Pneumonia and sore back and waist are treated by applying poultices to the affected areas, made with a decoction of mallow and quinoa flour (Zalles and De Lucca, 2006).

### 2.2.4. School breakfasts

In Ecuador, the United Nations World Food Programme began to include quinoa as part of their school program, representing a potential for increasing national demand (Jacobsen and Sherwood, 2002).

Peru also had the experience of "Andeanizing the school breakfast". This is the inclusion of Andean foods (among them quinoa) in breakfast rations offered by the country´s school centres. The experience achieved great results by involving and engaging different levels of government in its implementation. Among the lessons learned was the importance of insisting in a sensitization processes especially with large suppliers who did not in all cases maintain the formulas with quinoa and other Andean products (Tapia, 2000).

Therefore for its nutritional and therapeutic benefits, quinoa can be considered a complete, nutritious, healthy and highly recommended food, especially for children, pregnant women, coeliacs, women experiencing menopause, the elderly and convalescents, but also for athletes, vegetarians, diabetics, very stressed people and adults in general.

# CHAPTER 3

## Genetic diversity, varieties and germplasm banks

### 3.1. Genetic diversity and varieties

The Andean Region is considered one of the eight centres of crop origin and diversity. This is where there is the greatest genetic diversity of both wild and cultivated quinoa which can still be found in the wild and in the Andean farmer's fields.

Among Andean crops, quinoa has received most dedication and support in Ecuador, Peru and Bolivia. Assessments of the genetic variability available has allowed quinoa categorize into five major groups according to their adaptations and some highly heritable morphological traits, which are easily detectable and which are maintained throughout the whole area of distribution.

The five groups of quinoa according to Lescano (1989) and Tapia (1990) are:

1. **Sea level Quinoas**: Found in the areas of Linares and Concepción (Chile) at 36 ° South latitude. They are more or less robust plants, 1.0 to 1.4 m tall, with branched growth and produce transparent cream-colored grains (Chullpi type). These quinoas have great similarities with *Chenopodium nuttalliae* (Huahzontle) that is grown only in Mexico at 20 ° North Latitude.

2. **Valley Quinoas**: Those that adapt between 2500 to 3500 metres. They are characterized by their height -up to 2.5 m or more, and are greatly branching with lax inflorescences and are usually resistant to mildew (*Peronospora farinosa*).

3. **Altiplano Quinoas:** They develop in larger areas as monocultures and between 3600 and 3800 masl, in the area of the Peruvian-Bolivian Altiplano. This is the area in which the greatest variability of characters is found and the grains with the most specialized uses are produced. The plants grow to heights of 0.5 to 1.5 m, with a stem ending in a generally compact main panicle. This group contains the largest number of improved varieties and also those most susceptible to mildew when taken to wetter areas.

4. **Salt flat Quinoas**: They grow in salt flat areas to the south of the Bolivian Altiplano. The driest area has 300 mm of precipitation. They are grown as a single crop with spacing of 1 m x 1m in holes to make better use of the little humidity available. These quinoa have the largest grain size (>2.2 mm in diameter) and are known as "Royal Quinoa". The grains are characterized by a thick pericarp and high saponin content.

5. **Quinoas of the Yungas**: A small group of quinoas that have adapted to the conditions of the Bolivian Yungas at altitudes between 1,500 and 2,000 masl, and are characterized by a somewhat branched development. They are green plants which reach heights of up to 2.20 m and when they are in bloom the whole plant takes on an orange colour.

According to Mujica (1992) cultivated quinoas have a high genetic diversity, showing variability in the color of the plant, inflorescence and seed which confers them with a wide adaptability to different ecological conditions (soil, rainfall, temperature, altitude, resistance to frost, drought, salinity or acidity).

Of the main varieties known in the Andean Region, in Bolivia 22 varieties are obtained by genetic improvement through hybridization and selection (Table 3). There is also a significant complex of bitter varieties known as "Royal Quinoa" which includes several local races: Royal white, Mañiqueña, Huallata, Toledo, Pink Mok'o, Tres Hermanos, K'ellu, Orange Canchis, Pisankalla, Pink Pandela, Perlasa, Achachino, Hilo, White rose, Mok'o, Timsa, Lipeña, Chillpi Amapola, Pink Chillpi, Utusaya and Pink Canchis (Aroni et al., 2003).

In Peru the following varieties have been obtained: Yellow Maranganí, Kancolla, Juli White, Cheweca, Witulla, Salcedo-INIA, Iplla-INIA, Quillahuaman-INIA, Camacani I, Camacani II, Huariponcho, Chullpi, Coporaque Red, Ayacuchana-INIA, Huancayo, Hualhuas, Mantaro, Huacataz, Huacariz, Yanamango Pink, Namora, Tahuaco, Yocará, Wilacayuni, Pacus, Junín Pink, Junín White, Acostambo y Ayacuchana White (Mujica et al., 2004; Mujica, 1992).

In Ecuador the following varieties have been obtained: Tunkahuan, Ingapirca, Cochasqui, Imbaya, Chaucha, Tanlahua, Piartal, Porotoc, Chimborazo bitter, Imbabura bitter and Purple (Mujica et al. 2004; Tapia, 1990; Mujica, 1992).

According to Peralta (2006) the Tunkahuan variety is effective and is the most planted in the highlands of Ecuador, Peralta also indicates that in 2004 the variety Pata de Venado was released.

**Table 3.** Bolivian quinoa varieties obtained through genetic improvement

| N° | Variety | Source material | | Year | Institution |
|---|---|---|---|---|---|
| 1 | Sajama | 0547 | 0559 | 1967 | IBTA |
| 2 | Samaranti | Individual selection | | 1982 | IBTA |
| 3 | Huaranga | Selection S-67 | | 1982 | IBTA |
| 4 | Kamiri | S-67 | 0005 | 1986 | IBTA |
| 5 | Chucapaca | 0086 | 0005 | 1986 | IBTA |
| 6 | Sayaña | Sajama | 1513 | 1992 | IBTA |
| 7 | Ratuqui | 1489 | Kamiri | 1993 | IBTA |
| 8 | Robura | Individual selection | | 1994 | IBTA |
| 9 | Jiskitu | Individual selection | | 1994 | IBTA |
| 10 | Amilda | Individual selection | | 1994 | IBTA |
| 11 | Santa Maria | 1489 | Huaranga | 1996 | IBTA |
| 12 | Intinayra | Kamiri | F4(28)xH | 1996 | IBTA |
| 13 | Surumi | Sajama | Ch'iara | 1996 | IBTA |
| 14 | Jilata | L-350 | 1493 | 1996 | IBTA |
| 15 | Jumataqui | Kallcha | 26(85) | 1996 | IBTA |
| 16 | Patacamaya | Samaranti | Kaslala | 1996 | IBTA |
| 17 | Jacha Grano | 1489 | Huaranga | 2003 | PROINPA |
| 18 | Kosuña | 1489 | L-349 | 2005 | PROINPA |
| 19 | Kurmi | 1489 | Marangani | 2005 | PROINPA |
| 20 | Horizontes | 1489 | L-349 | 2007 | PROINPA |
| 21 | Aynoq'a | Selection L-118 | | 2007 | PROINPA |
| 22 | Blanquita | Selection L-320 | | 2007 | PROINPA |

Source: Espíndola and Bonifacio (1996); Bonifacio et al. (2006); Rojas-Beltrán et al. (2010)

In Colombia the varieties Nariño and Quitopampa sweet (Mujica et al. 2004; Tapia, 1990) were obtained, while Chile produced the varieties Baer, Lito, Faro and Picchaman (Tapia, 1990) and Argentina-the Jujuy White (Mujica, 1992).

### 3.2. Quinoa germplasm banks in the Andean Region

In order to protect the vast phenotypic and genotypic variability of quinoa of the Andean Region, since the 60's germplasm banks have been implemented throughout the Region, with universities and agricultural entities in charge of their management and conservation. The number of accessions stored in the Region is variable, Bolivian and Peruvian entities holding the greatest quinoa variability in their gene banks. According to available information, five countries in the Andean Region have germplasm banks where quinoa is preserved along with other Andean crops.

In Bolivia, there are six entities with gene banks which conserve more than 5,000 quinoa accessions:

- 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.

Bolivia´s main quinoa germplasm collection is preserved in the INIAF Toralapa Centre and forms part of the National Germplasm Bank of Andean Grains (Rojas et al., 2010b). It is home to a wide genetic variability and currently maintains 3121 accessions, both cultivated and wild, which were gathered from communities in the Altiplano and the valleys in the Bolivian departments of La Paz, Oruro, Potosi, Cochabamba, Chuquisaca and Tarija. It also has germplasm from Peru, Ecuador, Colombia, Argentina, Chile, Mexico and the United States (Table 4).

**Table 4.** Number and origin of the quinoa accessions preserved in the INIAF Germplasm Bank, Bolivia

| Country | Departament / Region | N° of Accesions | Subtotal |
|---|---|---|---|
| Bolivia | La Paz | 963 | 2300 |
| | Oruro | 617 | |
| | Potosi | 469 | |
| | Cochabamba | 124 | |
| | Chuquisaca | 108 | |
| | Tarija | 19 | |
| Peru | Ancash | 5 | 675 |
| | Junin | 18 | |
| | Ayacucho | 40 | |
| | Cusco | 36 | |
| | Puno | 567 | |
| | Ica | 9 | |
| Ecuador | North | 11 | 28 |
| | Centre | 17 | |
| Chile | North | 1 | 18 |
| | South | 17 | |
| Argentina | Jujuy | 16 | 16 |
| Mexico | North | 3 | 6 |
| | Centre | 3 | |
| USA | New Mexico | 1 | 1 |
| Denmark | | 2 | 2 |
| Netherlands | | 2 | 2 |
| England | | 2 | 2 |
| OAS | | 60 | 60 |
| NI* | | 11 | 11 |
| **Total** | | | **3121** |

* NI = Not Identifiied. Source Rojas et al. (2010b)

In Peru there are several germplasm centres in the Experimental Stations of the National Institute of Agricultural Research (INIA)- in Illpa (Puno), K'ayra 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 (Mujica, 1992, Bonifacio et al., 2004). According to Bravo and Catacora (2010), the Germplasm Bank at the Illpa Experimental Station in Puno holds 536 accessions of quinoa and is considered the largest collection in the country.

In the case of Ecuador, there is only the Santa Catalina Experimental Station of the National Institute of Agricultural Research - INIAP, which maintains 642 quinoa accessions (Peralta 2004), while in Colombia, there is the Obonuco-Nariño Experimental Station and at the National University of Bogotá (Lescano, 1994). Meanwhile Chile has a gene bank at the Institute of Plant Production and Health at the Austral University of Chile with 25 accessions, and in the North, Fuentes et al. (2006) report a germplasm collection of 59 quinoa accessions.

In order to demonstrate the wide genetic variability of quinoa available, presented below are the parameters of some interesting variables in the Bolivian quinoa collection (Rojas et al. 2001; Rojas, 2003; Rojas, 2008, Rojas et al., 2009):

- Colour of the plant before flowering (green, purple, mixed, red)
- Colour of the plant at physiological maturity (various intermediate colours between white, cream, yellow, orange, pink, red, purple, brown and black)
- Panicle shape (amaranthiform, glomerulate or intermediate)
- Panicle density (compact, lax or intermediate)
- Grain Color (66 colours of grain have been identified including white, cream, yellow, orange, pink, red, purple, brown and black) (Cayoja, 1996)
- Vegetative cycle (110 a 210 días)
- Grain yield per plant (48 to 250 g)
- Grain diameter (1.36 to 2.66 mm)
- Weight of 100 grains (0.12 to 0.60 g)
- Protein content of the grain (10.21 to 18.39%)
- Starch grain diameter (1.5 to 22 μ)

**Photo 1.** Variability of quinoa panicles and grain colour

# CHAPTER 4

## Agronomy and potential adaptability of quinoa

### 4.1. Botanical and taxonomic description

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. The main stem may be branched or not, depending on the ecotype, race, planting density and the environmental conditions in which it is grown. Its cross section is circular in the area near the root, becoming angular at the height of the branches and leaves. The branched habit is more common in races cultivated in the Andean valleys of Southern Peru and Bolivia, whereas the simple habit is observed in a few races grown in the Altiplano and many of the races of central and northern Peru and Ecuador (Gandarillas, 1968a; 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 lanceolate. Leaf colour ranges from green to red, through yellow and violet, depending on the nature and importance of the pigments. They are dentate, with up to 43 teeth on their margins, and they contain granules on their surface which give the appearance of being covered with sand- These granules contain cells rich in calcium oxalate and are able to retain a water film, which increases the relative humidity of the atmosphere surrounding the leaf thereby reducing transpiration (Tapia, 1990; Dizes and Boniface, 1992; Rojas, 2003).

The inflorescence is racemose, called a panicle because it has a more developed main axis which gives rise to secondary and in some cases tertiary axes. It was Cardenas (1944) who first grouped quinoas together according to their panicle shape: amaranthiform, glomerulate or intermediate, and created the name amaranthiform owing to its resemblance to the inflorescence of the genus Amaranthus. According to Gandarillas (1968a) panicle shape is genetically determined by a pair of genes, the glomerulate form being totally dominant over the amaranthiform, and it therefore seems doubtful to classify intermediate panicles.

The terminal panicle may be defined (completely differentiated from the rest of the plant) or branched (when there is no clear differentiation because the main stem has relatively long branches that give the panicle a distinctive conical shape). The panicle may also be loose or compact, which is determined by the length of the secondary axes and pedicels, being compact when both are short (Gandarillas, 1968a).

The flowers are very small and dense, which makes emasculation difficult, they are positioned in groups forming glomerules, are sessile, the same color as the sepals and can be hermaphrodite, pistillate or androsterile. Their five stamens have short filaments that sustain basifix anthers and surround the ovary, whose style is characterized by 2 or 3 feathery stigmas. The flowers remain open for a period ranging from 5 to 7 days. As they do not open simultaneously the duration of flowering has been determined as 12 to 15 days (Heisser and Nelson, 1974; Mujica, 1992; Lescano, 1994).

The fruit is an indehiscent achene containing a grain that can reach up to 2.66mm in diameter according to the variety (Rojas, 2003). According to Tapia (1990), the perigonium covers the seed and rubs off easily. The episperm surrounding the grain is composed of four layers, the outer layer which determines the color of the seed is rough, brittle, easily removed with water, and contains saponin.

With respect 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 (Cronquist 1995, Wilson 1980). The genus Chenopodium is the largest in the family Chenopodiaceae and has a worldwide distribution, with about 250 species (Giusti, 1970).

Within the genus Chenopodium there are several species which are cultivated as food plants: as grain producers in South America, Chenopodium quinoa Willd. and Chenopodium pallidicaule Aellen, as vegetables in Mexico Chenopodium nuttalliae Safford and Chenopodium ambrosioides L. , and as vegetables or medicines in South America- Chenopodium carnosolum Moq. and Chenopodium ambrosioides L.

The genus Chenopodium has been grown in various geographical areas of the world: Chenopodium album L. in Europe: Chenopodium giganteum D. Don, or spinach tree in Central Asia; Chenopodium berlandieri Moq. var. Nuttaliae in Central America, and Chenopodium quinoa and Chenopodium pallidicaule in South America. Also, Chenopodium berlandieri is distributed in North America and Chenopodium hircinum in the Andean and the Argentine pampa of South America (Fuentes et al., 2009).

Wild quinoa plants, which have a worldwide distribution, are those which have developed without human intervention, and have valuable genes that constitute a genetic potential that can be exploited in the future in various parts of the planet. Some taxa and populations are characterized by tolerating and resisting insects and diseases, frost and drought, and also possess favorable traits in terms of nutritional value and the duration of the productive cycle (Rojas et al. 2008; Del Castillo et al., 2007).

## 4.2. Cultivation and adaptability to climate change

The Andean Region and in particular the Altiplano shared by Peru and Bolivia has one of the most difficult ecologies for modern agriculture. However, quinoa survives in this ecological environment of low biotic interactions. Altiplano altitudinal limits are 3000 to 4000 metres above sea level, where soils are often alluvial and poorly drained (Espindola, 1986).

Rainfall varies greatly among the different areas of cultivation in South America. In the Ecuadorian Andean it is 600 to 880 mm, in the Mantaro Valley it is 400 to 500 mm and in the Lake Titicaca area it is 500 to 800 mm. However, as one moves south of the Altiplano of Bolivia and Northern Chile, precipitation decreases to levels of 50 to 100 mm, conditions in which quinoa is also produced. 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. On the other hand, quinoa is also produced between the eighth and ninth Region of Chile with rainfall above 2000 mm and sea level conditions.

Considering the conditions where quinoa is cultivated and the genetic variability available, quinoa has a remarkable adaptability to different agro-ecological zones. It adapts to different climates, the crop can grow at relative humidities from 40% to 88% humidity, and temperatures between 15 to 20 ° C are ideal for cultivation and can withstand temperatures from -4 ° C to 38 ° C. A water efficient plant, it is tolerant and resistant to lack of soil moisture, obtaining acceptable yields with rainfall of 100 to 200 mm.

As for cold tolerance, some quinoa varieties are tolerant to -5 ° C when they are in the grain forming stage (Espindola, 1986). According to Rea (1979), cited by Espindola (1986) cold tolerance depends on the stage of development when the frost occurs and the natural protection of the mountains. There are reports that quinoa survives temperatures of -7.8 ° C at early stages in the climatic conditions of Montecillo, Mexico, which is 2245 meters above sea level; Quinoa also tolerates soils of different texture and pH, even growing in highly acidic and alkaline soils (Mujica, 1988).

For these reasons quinoa is one of the few crops that develops without much difficulty in extreme climate and soil conditions. Its great adaptability to climate variability and its efficient use of water make quinoa an excellent alternative crop in the face of climate change which is altering the agricultural calendar and causing ever more extreme temperatures. The Bolivian National Institute of Agricultural and Forestry Innovation (INIAF) has ranked quinoa among the 21 seeds most resistant to climate change along with beans, corn, amaranth, onions and others.

All these factors have led to quinoa being extensively studied by national and international institutions . In addition to its recognized nutritional value, it has attracted the interest of researchers in North America (U.S. and Canada) and Europe (UK, France, Germany, Netherlands and Denmark), as well as other mountainous Regions of the world (Himalayas and Eastern Africa) (Risi, 1991), who have conducted adaptation studies and are currently planting and harvesting quinoa.

### 4.3. Production systems

The cultivation of quinoa in Bolivia dates back to pre-colonial times. The traditional farming system prevailed until the early 1970's: In the Southern Altiplano it was restricted to mountain slopes bordering the Uyuni and Coipasa salt flats; in Central and Northern Altiplano it was grown in small extensions as part of the rotation system with potatoes and fodder, and in the valleys it was planted as a border plant or in association with corn and legumes.

The cultivation of quinoa was at that time, as is is in much of the country today, developed by hand from planting to harvest. Families had access to diverse ecotypes or landraces of quinoa, the grains were produced according to requirement and for the preparation of different foods, and the most important thing about this practice was that most of the produce was destined for home use.

The opening of the international organic market and the consequent increase in quinoa prices over the last two decades has led to the relocation of quinoa production from the foothills to the plains in the case of Bolivia, to the extension of the agricultural borders in other countries of the Region and to the introduction of the crop to other Regions of the world. The challenges facing quinoa cultivation are closely linked to supplying the international market, whose expanding demand represents a significant economic alternative for the inhabitants of production areas.

### 4.3.1. Traditional and mechanical systems

Following is a description of the Bolivian experience in the management and organic production of quinoa in the traditional system and the advances that have been made in the mechanical system.

#### *Soil preparation*

In the Southern Altiplano the mechanical system (95%) is virtually replacing the traditional system (5%). In the Central and Northern Altiplano quinoa is grown in rotation with potatoes and the soil preparation of the previous year is taken advantage of whether it is mechanical or traditional although owing to current quinoa prices soils are now being enabled and prepared using the mechanical system. In the Andean valleys the traditional system prevails with respect to the mechanical system.

In the traditional system the soil is prepared with man-power using a tool called a Taquiza, Liukána, or Tank'ana to totally or partially remove the surface soil, depending on the production area. In the case of the Southern Altiplano conical mounds are made with a diameter of 25 to 30 cm and a height of 15 to 20 cm, although this system is generally performed on the slopes (Cossio 2005).

The mechanical system consists of preparing the ground with the use of a motorized plough. According to Cossio (2005) in the Southern Altiplano its use is limited on slopes. The use of the tractor has extended the agricultural frontier to flat terrain (pampa), by enabling virgin lands or “purumas” with irregular topography which because of the nature of the climate have fragile soils (without structure) with low water holding capacity (sandy loam).

#### *Sowing*

Sowing is one of the most important activities because the emergence of seedlings which impacts plant density and final yields depends on this stage. Quinoa seeds are sown at different times, depending on the place to be sown, the variety’s traits and soil moisture. These are also important factors in determining the sowing method to be used- manual or mechanical. In the Southern Altiplano the quinoa sowing period is from late August through mid-December, while in the Central and Northern Altiplano planting time is between October and November, depending on rainfall.

Traditional sowing is a task that is still practiced in both the Altiplano and the valleys. In the Central and Northern Altiplano seeds are sown in furrows and the seed is either broadcast or distributed as a continuous stream. Usually the distance between rows is 50 cm. In the Southern Altiplano after making a hole with the 'taquiza' until moist soil is reached, the seed is deposited and immediately covered with soil to a depth ranging from 4 to 10 cm. The distance from hole to hole varies from 1 to 1 . 20 m and the distance between the rows also varies from 1 to 1.20 m. In both systems the amount of seed sown can vary between 6 to 8 kg / ha.


**Photo 2.** Traditional and mechanical sowing of quinoa in the Southern Altiplano

**Mechanical sowing** in the Southern Altiplano is carried out by at least 70% of families and is performed with the Satiri drill. The drill has two furrowers with chutes through which the seed is fed. 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. This sowing system is efficient on uniform level ground, the product of a good fallow, and should be used on soils where moisture is at a depth of 10 to15 cm (Aroni 2005a).

## 4.4 Quinoa´s insect pests

During the vegetative period, the quinoa crop is affected by a wide range of insects, of which around 17 species have been identified. 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%.

**Photo 3.** Larvae of the quinoa moth and ticona complex

#### 4.4.1. The quinoa moth

The adult is a small moth about 8 to 9 mm in length with a wing span of 14 to 16 mm. It feeds on flower nectar and is not itself harmful to the quinoa crop. Females oviposit their miniscule eggs which measure 0.4 to 0.5 mm in length, are subglobulose in shape, smooth, creamy white at the time of oviposition and ash white two days before the larvae hatch. The larvae attack the crop in two generations: the first generation (November and December), consume and destroy the leaves and forming inflorescences, stick young leaves together and roll them up. The second generation (March-May) of larvae attack plants in the maturation phase, feeding on the forming and mature grains inside the panicles. In severe attacks the grain is pulverized and a white powder appears around the base of the plant. This second generation causes the most economic damage to the quinoa crop.

#### 4.4.2. Ticona complex

The adult is a nocturnal butterfly that is attracted by the light. It has a short body and sturdy covering of scales or dark brown hair. It has a wing span of 40 mm. The forewings have grey brown wings with wavy transverse stripes with small dark or light spots. The newly emerged larvae are very active. They scrape the mesophyll of the leaves and eat the parenchyma leaving it in the form of transparent windows. From the third stage when their jaws are more developed they cut the young plants at ground height causing them to collapse and die. When the larval population is high they destroy buds, flowers and glomerules, in addition to drilling shoots and stems. The fourth and fifth larval stages are the most dangerous for their voracious and selective appetite.

#### 4.4.3. Work aimed at reducing insect pest populations

There are several projects being carried out with the aim of reducing pest populations of quinoa crops and there have been some important technological advances to address this biotic factor. According to Saravia and Quispe (1995), the studies and technologies that are available are: 1) pest tolerant or pest resistant genotypes, 2) knowledge of the pests´ life cycles, 3) the quinoa pests natural enemies have been identified as has the percentage of parasitism, 4) knowledge of population dynamics of quinoa pests, 5) pest control with natural extracts and bio-insecticides, 6) level of economic damage and 7) pest control strategies. Recently, pheromones and bio-products are being used.

### 4.5. Harvest and post-harvest

Harvesting and post harvest activities are of great importance to the whole quinoa production process. Grain quality, the incorporation of organic matter into the soil and the reduction of processing costs depends on these activities. Harvesting and post-harvest work includes cutting, drying, threshing, winnowing and grain storage. The application of good practices produces a grain that meets the quality parameters.

### 4.5.1. Harvest

The optimum time for cutting plants depends on many factors: the variety, soil type, humidity and prevailing temperature. Usually the quinoa´s leaves turn yellow or red depending on the variety and the grains can be seen in the panicle through the opening of the perigonium which is characteristic at this stage of physiological maturity (Aroni, 2005b). Another method is to tap the panicle with the hand, if the grains fall harvesting can begin.

Usually there are three ways to harvest the plants: traditional uprooting, harvesting with a sickle and semi-mechanical harvest.

Traditional uprooting: this method consists in pulling out the plants by hand, selecting the mature panicles from each hole or row, and proceeding to shake or hit the root on the knees in order to reduce the presence of earth clods and pebbles. The disadvantage of this method is that it does not leave the root in the soil as organic matter and also contributes to soil erosion, lowering soil fertility. This method also leads to soil being mixed with the grain, increasing the presence of impurities in threshing.

**Photo 4.** Cutting with sickle and mechanical mower - Southern Altiplano

Manual harvesting with a sickle: consists in cutting the plant between 10 and 15 cm above the soil and leaving the stubble in the soil thus helping soil conservation. The plants must be cut at the right time, ie when the panicles still resist the loss of grain upon handling, because when the plants exceed maturity there are increased grain losses. The disadvantage of this method is that it cannot be used on very sandy soils and it is difficult to cut large plants because of the thickness of the stem.

Semi-mechanical harvesting: involves cutting the plants with a mechanical mower. Its use is made easier when the plants are arranged in holes or furrows. According to Aroni (2005) the advantage of this method is that the harvest is fast and leaves the stem and roots in the soil for incorporation as organic matter. Experiences show that with the participation of 4 people 2.5 ha / day can be cut.

### 4.5.2. Post harvest

This activity through which the grain is obtained includes drying or stacking, threshing, venting and storage.

a) ***Drying or stacking: involves arranging the plants in stacks immediately after cutting.***

*There are three methods of stacking or drying: Arcos, Tauca and Chucus (Aroni, 2005b):*

- Arcos

This stacking method involves stacking the plants in the form of an x (cross) resting on a base of thola or other native species with the panicles leaning upwards. Drying is facilitated because there is more air circulation and the ears are sufficiently exposed to the sun for drying. This method is time consuming to prepare but in this way the harvest can be dried in less than three weeks.

**Photo 5.** Drying methods: Arcos and Taucas – Southern Altiplano

- Taucas

Consist of building mounds or stacks of plants with the panicles ordered towards the same side and on a piece of material that can be canvas or nylon. The length can be 10 to 15 m and a height of 1m, this method may take a little longer to dry, but because of its concentration in one place it facilitates threshing. The disadvantages of this method are that drying is nonuniform, and the harvest is exposed to rain and wind.

- Chucus

These are more or less cone shaped mounds of quinoa plants, which are scattered throughout the whole field. The mounds are made by standing the plants up in a circle with the panicles toward the top to give more stability to the chucu. They are usually tied in the middle with a rope. This method permits faster drying.

b) ***Threshing: this consists in the separation of grains from the panicle.***

***There are several different methods of threshing: manual, semi-mechanical, mechanical and direct threshing (Aroni, 2005b):***

- Manual threshing

Is one of the most difficult tasks in quinoa production, and is practiced in places inaccessible to vehicles. For this method it is necessary to prepare in advance the 'Takta' which consists of a platform of clay, water and “jipi” (or some farmers use canvas instead) upon which the dried plants are threshed. A stick called 'Huajtana' is used to beat the plants and the resulting plant material is then coarsely sifted and then winnowed to obtain the grain. The yield for a day´s work is 1.5 quintals / day.

**Photo 6.** Threshing methods: Manual and with Tractor – Southern Altiplano

- Semi-mechanical threshing

In the Southern Altiplano the use of vehicles (tractors, trucks, etc.) has been adopted to carry out this method of threshing. A tarpaulin is extended on the ground and on top the dried plants are placed in two parallel, longitudinal piles over which the wheels of the motor pass. The panicles are placed towards the inside of the two rows so that in multiple passes the vehicle is able to separate the grains. This method processes about 10 qq in 55 minutes. The difficulty is in the following sifting and winnowing which are performed manually.

- Mechanical threshing

In the Southern Altiplano threshers such as the “Vencedora” and “Alvan Blash” are used, which after adjusting their hulling and sieving systems achieve yields of 10quintals / hour and 7 qq / hour, respectively. In both cases the cleaning is 95%. The “Herrandina” thresher has also been tried with a yield of 123 kg / hour.

**Photo 7.** Threshing Method: Mechanical threshing – Central Altiplano

c) ***Winnowing: This work involves the separation of 'Jipi' or perigonium and plant waste from the commercial grain.***

***There are three methods: traditional, improved manual and mechanical (Aroni, 2005b):***

- Traditional winnowing

Is carried out manually on a blanket or traditional textile with the help of a small plate, this method of winnowing is dependent on the presence of moderate winds. The average yield is 4 qq. / day

**Photo 8.** Winnowing methods: Traditional and Improved Manual – Southern Altiplano

- Improved Manual Winnowing

Is performed with a machine or prototype such as that shown in Photo 8, which has an air flow regulator and separates the quinoa grain from the 'Jipi', 'Chiñi' and plant waste. This machine yields 6 qq / hour.

- Mechanical winnowing

Mechanical winnowing has been in use for the last six years, yielding 5 to 8 qq / hour depending mainly on the amount of 'Jipi' which the material to be winnowed contains.

d) ***Storage:*** To maintain product quality, storage should be carried out in a clean, dry and ventilated environment. It is recommended that the grain is stored in sacks made of woven llama wool, or new or good condition polypropylene bags. The filled bags should be stacked properly on a wooden pallet.

# CHAPTER 5

## Derived products and industrial potential of quinoa

In 1996, quinoa was classified by FAO as one of the most promising crops for humanity not only for its greatly beneficial properties and its many uses, but also because it is considered an alternative to solve the serious problems of human nutrition.

There are several derived quinoa products such as puffed quinoa, flour, pasta, flakes, granola, energy bars, etc. Nevertheless in recent years there has been ever more research into the development of combined products in order to make quinoa consumption more attractive.

However it is noteworthy that more elaborate products or products whose fabrication requires the use of advanced technologies have not yet been exploited, as is the case of oil extraction, starch, saponin, protein concentrates, milk, extraction of colourings from the leaves and seeds, etc. These products are considered the economic potential of quinoa as they make use of not only its nutritious traits but also its physicochemical traits which reach beyond the food industry offering products to the chemical, pharmaceutical and cosmetic industries.

### 5.1. Food preparation

Quinoa like other Andean grains, is used in many different ways, it has traditional and non-traditional uses as well as value-added industrial innovations generated through research which are now commercially available.

#### 5.1.1. Traditional uses

As a result of interviews with families who conserve and produce quinoa in the Altiplano, 35 food preparations of quinoa have been identified. Among these are soups and desserts, pastries, drinks and dry snacks. The diet of rural families include a variety of Kispiñas, P'esques, Soups, Mucuna, Pito (toasted flour) and refreshments, and on special occasions they prepare non-traditional foods like biscuits, cakes, doughnuts and juice. The preparation of these foods varies with the seasons and the agricultural activities which are carried out. They are often eaten at breakfast, lunch, dinner or as a snack.

The following is a brief description of traditional preparations that are eaten in Altiplano communities (Pacosillo and Chura, 2002; Vidaurre et al., 2005, Flores et al. 2008; Apaza et al., 2008):

- ***Quinoa soup:*** Not very thick cooked quinoa with meat or dried meat, tubers and vegetables.
- ***Lawa***: A semi thick “Mazamorra” (porridge like preparation) with raw flour, water with lime and animal fat.
- ***P'esque:*** Quinoa grain cooked with water, without salt, served with either milk or grated cheese according to the availability of these additions.
- ***Kispiña:*** Steamed buns of different shapes and sizes.
- ***Tacti o tactacho:*** Fried buns, a kind of doughnut made with flour and llama fat.

- ***Mucuna:*** Steam cooked balls made from quinoa flour with seasoning in the centre similar to tamales or humitas.
- ***Phiri:*** Roasted and slightly dampened rough quinoa flour.
- ***Phisara:*** Lightly roasted and cooked quinoa grain.
- **Q'usa:** Quinoa chicha, a macerated cold drink
- ***El Ullphu, Ullphi:*** Cold drink prepared with roasted quinoa flour diluted in water with sugar added to taste.
- ***Kaswira de quinua:*** Flattened bread fried in oil, made with katahui (lime) and white quinoa.
- ***Kaswira de ajara:*** Flattened bread fried in oil, made with katahui (lime) and black quinoa or ajara
- ***K'api kispiña***: Steamed bun, made with quinoa ground in a K `ona and cooked in a clay pot, common in the feast of All Saints.
- ***Turucha quispiña o Polonca:*** Large steamed breads, made with katahui and quinoa lightly ground (chama) in a K `ona ,and cooked in a clay pot.
- ***Mululsito quispiña:*** Steamed bread, made with katahui and quinoa flour, cooked in a clay pot, smaller than Kispiñas.
- ***Quichi quispiña:*** Steamed and fried bread, made with katahui and quinoa flour, fried in a pan.
- ***Juchacha:*** Andean soup based on ground quinoa and katahui, accompanied by roasted barley flour.
- ***Chiwa:*** Young leaves of quinoa called **Lliccha** in Quechua and **Chiwa** in Aymara, are used as a vegetable in the preparation of soups and salads. The leaves are rich in vitamins and minerals, especially calcium, phosphorus and iron.

### 5.1.2. Non traditional uses

The non traditional foods which are eaten are tawas, pancakes, doughnuts, juice, api, bread, biscuits, chili and nectar (Table 5). These products are new alternatives to increase the use of quinoa in rural and urban families, since they are prepared from quinoa flour instead of wheat flour.

Quinoas culinary plasticity and its wealth of traditional preparations allow it to be integrated in international cuisine to create highly nutritious menus which are competitive in global markets whilst also valuing traditions.

**Table 5.** Traditional and non traditional foods made with quinoa

| Preparation | Type of food | |
|---|---|---|
| Soups and desserts | • Quinoa soup<br>• Lawa (allpi)<br>• Huaricha<br>• Juchacha<br>• Chiwa de quinua<br>• P'esque with ahugado | • Mazamorra<br>• Phiri<br>• Phisara<br>• P'esque Huracha<br>• P’esque with milk<br>• P’esque with cheese |
| Doughs | • Kispiña<br>• Mucuna<br>• Doughnuts<br>• Bread<br>• Buscuits<br>• Kispiña de ajara<br>• Quinoa cakes<br>• Quinoa Tortillas<br>• Tacti or tactacho<br>• Mululsito quispiña | • Kispiña de ajara<br>• K'api kispiña<br>• Acu kispiña<br>• Jupha t'anta<br>• Quinoa Kaswira<br>• Quinoa cake<br>• Turucha Kispiña<br>• Quichi quispiña |
| Drinks | • Juice (ullpu)<br>• Q’usa (chicha)<br>• Apí | • Quinua with milk<br>• Quinoa juice |
| Snacks | • Roasted quinoa flour | |

### 5.1.3. New uses or innovations

Quinoa can be combined with legumes such as dried broad beans, beans and tarwi to improve the quality of the diet especially for preschool and school children through the school breakfast. Currently several processed or semi-processed sub products are available, although generally at higher prices so that in many cases they become unaffordable for most people.

Among the processed or semi-processed products, are the ready-to-eat cereals which are usually eaten as breakfast. Among these are puffed, extruded, flaked, grated and hot cereals, the last of which are prepared by adding a hot liquid and are finally reconstituted as porridges.

**Photo 9.** Range of quinoa based products in the Bolivian organic market

Other references indicate that whole grains and quinoa flour can be used to prepare almost all products of the milling industry. Different trials in the Andean Region and beyond have demonstrated the feasibility of adding 10, 15, 20 or even 40% quinoa flour to bread, up to 40% in pasta, up to 60% in cakes and up to 70% in buscuits (Nieto and Wood, 1982; Ballon et al. 1982; Ruales and Nair, 1992; Nieto Soria, 1991; Jacobsen, 1993). However quinoa´s flour yield ranges from 62% for grain which has not had the saponin removed, up to 83% for desaponified quinoa, considering wholegrain flour (Briceño and Scarpati, 1982). The yield of extra fine flour was only 33 to 46% depending on the variety (Nieto and Wood 1982). The main advantage of quinoa as a supplement in the flour industry, is meeting an  increase in the international demand for gluten-free products (Jacobsen, 1993).

Currently there is a need for producing high quality protein rich foods. In quinoa the protein is concentrated mainly in the embryo of the seed which contains up to 45% protein.

## 5.2. Industrial and other potential

Quinoa is a product from which a series of subproducts can be obtained for use as food, in cosmetics, pharmaceuticals and other uses as shown in Figure 2.

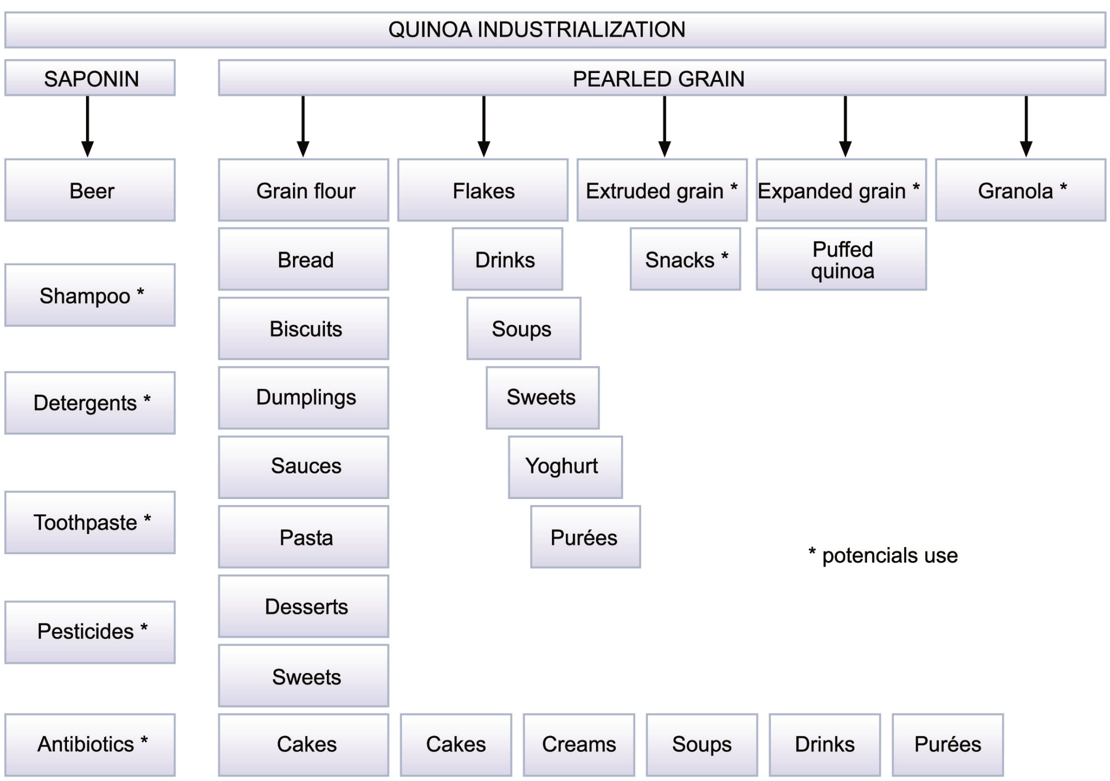


**Figure 2.** Uses of quinoa grain  (Montoya Restrepo et al. 2005)

Robalino, and Peñaloza (1988) demonstrated the preparation of tempeh (vegetable meat), based on quinoa grain. The process used was similar to that used for the preparation of soy meat, ie fermentation with Rhizopus oligosporus, whose beneficial action on lipids, proteins and trypsin inhibitors, along with the aroma and flavour developed, gave a special characteristic to the product, which was greatly appreciated by the panel of tasters. The cooking time for this product was only 5 minutes at 92 ° C and the incubation time was 28 h. Soria et al. (1990) also described the preparation of quinoa-based tempeh, whose final product is a solid white paste, with a pleasant smell, composed of quinoa grains joined by the mycelium of the fungus.

Other products made of quinoa, described by Nieto Soria (1991) are: “quinoa ham”, precooked flour, jellied milk made with quinoa among others.

Ahamed et al. (1998) mention that quinoa starch has excellent freeze-thaw stability and is resistant to retrogradation. These starches could provide an interesting alternative to replace chemically modified starches. Quinoa starch has particular potential for use in industry due to the small size of the starch granule, for example in the production of aerosols, pastas, carbonless copy paper, nutritious desserts, excipients in the plastic industry, talcs and anti-offset powders.

### 5.2.1. Saponins

Saponins are found in many plant species, eg spinach, asparagus, alfalfa and soy beans. The saponin content in quinoa varies between 0.1 and 5%. The pericarp of the quinoa grain contains saponin, which gives a bitter taste and must be eliminated so that the grain can be consumed. Saponins are characterized, in addition to their bitter taste, by foaming in aqueous solutions. Foams are stable at very low concentrations, 0.1%, and therefore saponins have applications in beverages, shampoo, soaps etc.

Saponins are organic substances of mixed origin, as they come from both triterpenoid glycosides (with a slightly acid reaction), as well as steroid derivatives of perhydro 1.2 cyclopentano phenanthrene. These molecules are concentrated in the hull of the grain and represent the main antinutritional factor. Saponins have no well-defined chemical formula for the dual source explained above, however, in general, the following basic skeleton is suggested: CnH2n-8O10 (with $n \geq 5$).

Saponins extracted from bitter quinoa can be used in the pharmaceutical industry, whose interest in saponins is based on their hypocholesterolemic effects and their ability to induce changes in intestinal permeability, which can assist in the absorption of particular medications. Saponins also have antibiotic and antifungal properties as well as other pharmacological attributes.

Because of the differential toxicity of saponins in various organisms, their use as potent natural insecticides that do not generate adverse effects on humans or large animals has been researched, emphasizing their potential for use in integrated programs of pest control. The use of quinoa saponin as a bio-insecticide was tested successfully in Bolivia (Vera et al., 1997).

### 5.2.2. Quinoa Multifunctionality

The inclusion of 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. The promotion of Andean tourism corridors, Inca routes or other attractive circuits in the Region, would allow quinoa and its diversity within the various production systems of the Andean zone to be displayed. Including quinoa in the menus that accompany these trips allows visitors to discover the traditional flavours and preparations and to appreciate identities, cultures, knowledge and traditions. In several countries of the Andean Region the conservation of biodiversity is being promoted as a local development strategy.

**Photo 10.** Quinoa juice sales in tourist zone of Bolivias Southern Altiplano

# CHAPTER 6

## Economic aspects of quinoa in the Andean Zone and he world

### 6.1. Cultivated area and quinoa production

Because of the obvious importance of the Andean Region in the production of this crop, the following sections will first analyze quinoa´s production characteristics in the Andean Region and then in the rest of the world.

#### 6.1.1. Cultivated area and the production of quinoa in the Andean Region

The largest areas of quinoa production in the Andean Region are in Bolivia, Peru and Ecuador. Other countries such as Chile report areas of 1,474 ha, 90% of which is in the district of Colchane in the Region of Tarapaca (Becares and Bazile, 2009). Below are two figures (fig.3 and fig.4 ) with referential data for the surface and volume of crop production for the Region of analysis according to the FAO database (2011).

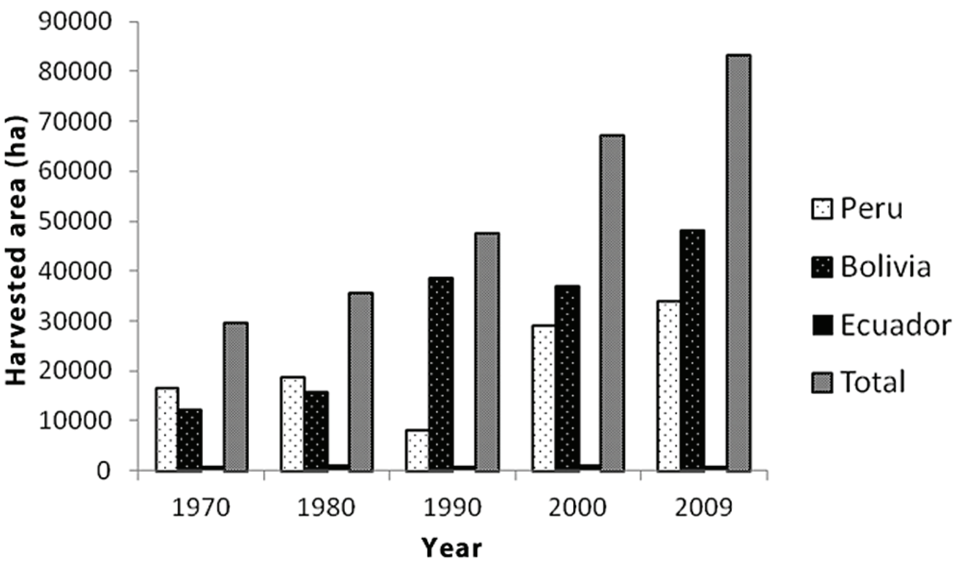


**Figure 3.** Area of quinoa harvested in three Andean countries in 5 referential years.

**Source: Based on data from FAOSTAT (2011).**

Until the beginning of the 80´s the area of quinoa harvested in the Andean Region did not exceed 36,000 ha. This production area is divided mainly between Bolivia and Peru and to a lesser extent (4%) Ecuador. (Fig. 3).

By the early 90's there was a significant increase in Bolivia's area of quinoa production: from 15,000 ha in 1980, to nearly 40,000 in 1990 due to the implementation of mechanical tillage of the soil around the Uyuni salt flat (Laguna. 2003). In the same period the production area in Peru was impaired due to the effects of El Niño with reported losses of up to 80% of the quinoa crop in Puno in the crop year 1982-1983 (Zavala and Caputo. 1985; Agrodata and CEPES. 1997). Effects were also seen to a lesser extent in Ecuador.



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In the year 2000 the area of quinoa production in the Andean Region increased to more than 67,000 ha, with a marked increase of 20,000 ha in Peru's production area and a stabilization of the areas under cultivation in Bolivia and Ecuador. The expansion of the agricultural frontier with quinoa in Peru is a result of national policy to promote production and export (Laguna 2003, Sukkah and Sukkah Apaza Apaza. 2008).

It can be seen that in recent years the productive area of quinoa is growing. FAO reports that in the Andean Region in 2009, 83,000 ha of quinoa were produced in the Region (FAO, 2011). This trend occurs in the main producer countries, more perceptibly in Bolivia and more moderately in Peru (31% and 18% more surface area compared to 2000, respectively).

Until 1980 the production of quinoa in the Andean Region was more than 25,000 t this production volume coming from the two main producer countries (Bolivia and Peru). (fig.4)

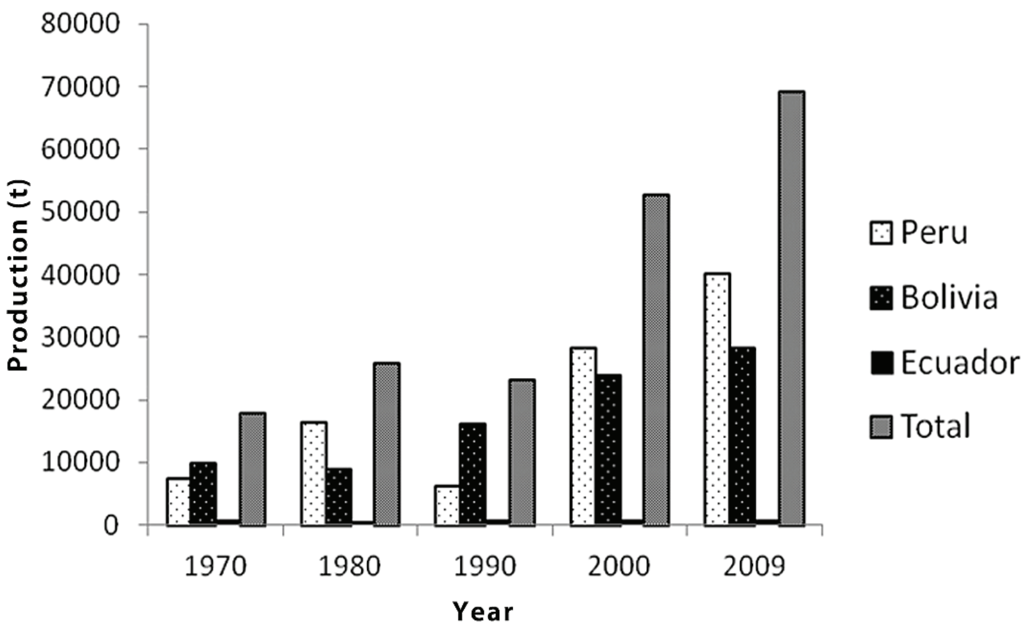


**Figure 4. Quinoa** production in three Andean countries in five referential years
**Source: Based on data from FAOSTAT (FAO, 2011).**

In 1990 the effects of El Niño previously mentioned could be observed on quinoa production. Peru's production was reduced by 60% compared with production in 1980. In Bolivia emerging markets encouraged an increase in production area of 147% compared with the year 1980 (see above), despite this, production in this period of analysis increased by only 80%, showing that this countries yields are still low (507 kg / ha) (Bolivian National Statistics Institute 2011).

In 2000, production in the Andean Region duplicated with respect to the years 1980 and 1990 and exceeded 50,000 t due to a marked increase in production in Peru and Bolivia (350% and 48% more output than 1990, respectively) in response to demand from new markets. This year Peru's production (28 191 t) exceeded that of Bolivia (23,785 t) despite having less productive area, however, an important volume of quinoa which is not registered leave from Bolivia through Peru.

In recent years (2009) production in the Andean Region was about 70,000 t with almost 40,000 t produced by Peru, 28,000 t by Bolivia and 746 t by Ecuador.

These data show that the major producer of quinoa in the Andean Region and the world are Peru and Bolivia. Until 2008 the production of both countries accounted for 92% of quinoa produced in the world (Suca Apaza y Suca Apaza, 2008). Currently (2009) according to FAO statistics, the two countries produce 68,000 t. Production in these two countries has historically been variable. In Peru, the political climate has had a big impact on production levels, the genetic materials that are grown are more vulnerable, but government involvement in production policies have had an interesting effect on the promotion of this crop . Bolivia produces more rustic varieties with a more attractive grain size that meet market demand but with low yields which on average do not exceed 600 kg / ha[1.] High production levels in this country primarily reflect the intense expansion of the agricultural frontier in the last 30 years. Meanwhile Ecuador shows different levels of quinoa production, according to FAO statistics in the years analyzed, the surface area does not exceed 1,300 ha and production is variable- around 1,000 t.

### 6.1.2. Cultivated area and production of quinoa in the rest of the world

Behind Peru and Bolivia the largest producers worldwide of quinoa are the United States, Ecuador and Canada with about 10% of global production volumes. The United States produces 3,000 MT annually, representing 6% of world production. Production in Canada is more variable- between 30 and 1,000 MT (CAF et al. 2001, Laguna 2003). The area reported in both countries is 2,300 ha (Laguna, 2003; Sukkah and Sukkah ApazaApaza, 2008).

The CAF et al. (2001) reported a production of 210 MT for Europe. Recently, the Agricultural Cooperative of the Loire Valley (CAPL) in France reported 200 ha of quinoa with yields of 1080 kg / ha, as a result of 20 years of work. The idea of this project is to ensure the consumption of quinoa in this country, which will continue fine-tuning aspects of production in order to reach its goal (GoodPlanet.info, 2011).

More detail is provided in Chapter 7 about the areas of quinoa expansion outside the Andean Region.

## 6.2. Number of producers

In Bolivia in 2001 there were more than 35,000 hectares planted with quinoa in approximately 70,000 production units. Of the total agricultural units: 55,000 produce irregularly for subsistence (with little surplus for trade), 13,000 produce permanently for the market and subsistence and 2,000 produce mainly for the market. This study found that quinoa contributed 2.35% to the value of agricultural GDP originating in family agriculture and the recorded exports accounted for 4.5% of exports of Bolivian products from family agriculture (CAF et al., 2001).

80% of these units are in the Northern and Central Altiplano in small production areas. For these producers, quinoa is important in terms of nutrition and food security, since between 70 and 85% of its production is destined for home use and the remainder is sold (Brenes et al., 2001, Pérez2001, Cáceres et al., 2007).

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[1] Average yield in 20 years (1990-2009): 580 kg/ha (estimation based on data from INE (Bolivian Nacional Institute of Statistics 2011)

The Southern Altiplano contains 15,000 farmers cataloged mostly as poor, 60% of their produce is destined for trade and export, accounting for 55 to 85% of the populations income. When agriculture is not the only source of household income, quinoa makes a contribution of 35 to 50%. These amounts are more evident when the head of household is female and has little livestock (CAF et al., 2001, Pérez, 2001, Rojas et al., 2004).

The land tenure of productive units in Peru is reduced (areas smaller than 3,000 m2), these are located mostly in the mountains with the participation of approximately 60,000 producers. An analysis by Suca Apaza reported that these productive units generate little profit which suggests a production logic based on the maintenance of the farm to ensure food security (CAF et al., 2001, Suca Apaza y Suca Apaza, 2008).

In Ecuador, 90% of the quinoa is produced by small farmers in the Sierra (Mountains), one of the poorest areas of the Region, with a significant presence of women. In this sense quinoa is a strategic crop to support vulnerable populations and areas (Jacobsen and Sherwood, 2002). In 2001 it was reported that 2,500 farmers were involved in the production of quinoa (CAF et al., 2001). The contribution of quinoa cultivation to Ecuador's agricultural GDP was estimated at 0.05%, almost insignificant due to low production volume compared to other agricultural products in this country (Vasconez, 2009).

In the main production area of Chile there are less than 200 farmers growing quinoa with an estimated area of 8 ha in 2007 (in the 90's areas per producer were 1.6 ha). Producers mostly exceed 60 years of age and there is migration of 75% of the young inhabitants of the Region (Becares and Bazile, 2009).

In the ninth Region of Chile women grow quinoa in gardens near their homes as a legacy of the Mapuche culture. Many women keep their crops as a gift or bequest upon marrying and most cultivate for their own use. Thus, in recent years there have been efforts to promote foods with their own-identity (Becares and Bazile, 2009).

## 6.3. General costs, incomes and profits of quinoa production

Quinoa, as mentioned above, is a highly rustic crop that requires little investment in production inputs. The main profits are obtained through organic production and the use of some organic products in its production is now being considered. Overall production costs for one hectare of organic quinoa do not reach one thousand dollars (US $ 910) as the crop does not require major investments in cultivation procedures, and organic control products and fertilizers are inexpensive. Considering an average yield of 760 kg / ha and a selling price of $ 120 per quintal, the gross income is US $ 2,040,00, generating a total profit of US $ 1,130,00 per ha / year. However, it is important to note that in the case of associated producers that can be articulated horizontally with marketers, sale prices of quinoa grain can be greater with ranges that vary between $ 120 and $ 180 per quintal.

**Table 6.** Costs, incomes and profits of quinoa production (Costs expressed in US$/ha, on 30/12/2010)

| ACTIVITY | | UNIT | QUANTITY | PRICE per unit | EXPENSES | INCOME |
|---|---|---|---|---|---|---|
| Land preparation | | | | | 135.00 | 0.00 |
| | Acquisition of manure | qq | 5 | 7.00 | 35.00 | |
| | Application of manure | Daily wage | 2 | 10.00 | 20.00 | |
| | Manual plowing | Daily wage | 8 | 10.00 | 80.00 | |
| Sowing | | | | | 270.00 | 0.00 |
| | Seed | Kg | 8 | 5.00 | 40.00 | |
| | Manual sowing | Daily wage | 6 | 10.00 | 60.00 | |
| Cultivation procedures | | | | | 195.00 | 0.00 |
| | Acquisition of Pest control | Applications | 3 | 25.00 | 75.00 | |
| | Application of Pest control | Daily wage | 12 | 10.00 | 120.00 | |
| Harvest | | | | | 123.00 | 0.00 |
| | Cutting and stacking | Daily wage | 6 | 10.00 | 60.00 | |
| | Transport | qq | 18 | 1.00 | 18.00 | |
| | Semimechanical threshing | Machine hours | 1.5 | 30.00 | 45.00 | |
| Post harvest | | | | | 187.00 | 2,040.00 |
| | Milling | qq | 17 | 11.00 | 187.00 | |
| | Sale | qq | 17 | 120.00 | | 2,040.00 |
| Subtotals | | | | | 910.00 | 2,040.00 |
| TOTAL PROFITS | | | | | | 1,130.00 |

The income generated by quinoa production may be low compared to other high value crops, but it is important to note that quinoa is produced in places where other crops do not thrive. Additionally, given the hardiness of the crop, the risk of losses due to adverse conditions is significantly lower compared to other crops.

In addition considering that most of the farmers produce 10 to 20 hectares per year, allowing them to receive incomes above $ 10,000 US / year. (Table 6).

## 6.4. Main export destinations

For 2009, FAO reported 48,136 ha of harvested quinoa in Bolivia. In the same year, the production volumes were between 28,000 MT (FAO) and 29,000 MT (INE) of which half was exported (51%) generating a value that exceeds $ 43 million[2] (IBCE, 2010 ). The remainder was sold on informal international markets (as unprocessed product via Desaguadero[3]) and to a lesser extent on the domestic market. The average quinoa consumption in Bolivia is estimated at 4.7 kg / person / year[4], with Oruro and Sucre being the areas which consume the most (CEPROBOL 2007). Departments such as Potosí which produce quinoa consume less than 2.5 kg / person / year (Borja and Soraide, 2007).

[2] The export entry corresponds to the heading "other quinoas¨ (*Chenopodium quinoa*) and is considered as the quinoa grain itself. Derived products have not been considered in this analysis.
[3] Population located on the shores of Lake Titicaca on the border with Peru.
[4] Compared to potato: 100 kg/person/year; pasta: 38 kg/person/year; or rice: 22 kg/person/year.

One of the most important destinations of Royal quinoa is export: Bolivia is the largest exporter of quinoa in the world followed by Peru and Ecuador (Pérez, 2001, Laguna, 2003, FAO, 2011).

In 2009 the major importers of Bolivian quinoa grain[5] were: United States (45% of Bolivian exports), France (16%), Netherlands (13%), Germany, Canada, Israel, Brazil and the UK. Bolivia also exports quinoa flour mainly to Brazil, Chile and the Netherlands, or flaked grains to Brazil, Canada and the United States and groats and semolina to Chile (IBCE, 2009, Bolivian Foreign Trade Institute, 2010).

The organic niche market absorbs a significant percentage of Bolivian quinoa exports, which is marketed by companies and associated producers (ANAPQUI, CECAOT, IRUPANA, SAITE, Quinoa Food, Andean Valley, among others).

According to IBCE (Bolivian Institute of Foreign Trade 2010) data, the price of organic quinoa was US $ 3.1 / kg for the year 2010. In previous years the price of organic quinoa reached US $ 3.6 / kg. The IBCE also indicates that by 2009 the price of conventional quinoa grain (US $ 2.3 / kg) was five times more than soybeans (US $ 0.4 / kg) and wheat.

Exports from Peru and Ecuador have a marginal role in the world market. In 2007, Peru exported volumes somewhat greater than 400 MT of quinoa grain to the United States (87%), Finland (8%) and Germany (4%) with values equivalent to US $552,000 (PROMPERU Peru's Export and Tourism Promotion Committee, 2008). In 2008 Ecuador displayed similar export levels: 304 MT worth US $557,000 (FAO, 2011).

There is no doubt that Bolivia leads exports mainly due to the quality of grain produced by the "Royal" type, which does not occur with the same characteristics in other countries in the Region (Laguna, 2003).

## 6.5. Consumer trends

Consumers mostly concentrated in North America and Europe have a tendency to greater interest in health care, environment and social equity. In this sense the niche market for organic and fair trade products offers interesting alternatives and better producer prices.

In the Andean countries there is a bewildering variety of preparations for the consumption of quinoa (Jacobsen et al. 2003; Astudillo, 2007) which comes from various different cultures and traditions. Countries like Peru, which import large quantities of quinoa from its neighboring country (Bolivia), have high levels of domestic use. Bolivian "Royal Quinoa" is imported to Peru primarily for marketing, processing and consumption in local markets, volumes are difficult to quantify because of the absence of records (Laguna, 2003). It is also known that 60% of its production is for home use by the producers and 40% is sold mainly in local markets and to a lesser extent in international markets (Suca Apaza y Suca Apaza, 2008).

[5] Data under the heading "other quinoas" (*Chenopodium quinoa*), or processed quinoa grain

In Bolivia, a country that identifies with this Andean grain because of their origin, traditions and exports, it is the lower stratum that eats quinoa. Areas which produce quinoa for sale present a clear downward trend in consumption due to the prioritization of exports and the difficulty of the milling process for household consumption (Astudillo, 2007). Nationally it was reported that consumption does not exceed 5 kg / person / year, despite being the highest per capita consumption worldwide, these levels are considered low even taking into account the population and consumption levels of other foods.

In countries (such as Peru and Bolivia) where malnutrition levels are high, it is essential to boost quinoa consumption in order to benefit from its exceptional nutritional properties.

# CHAPTER 7

## Expansion of quinoa cultivation to countries outside the Andean Region

The cultivation of quinoa transcended continental boundaries when in 1970 material was taken to England and Sweden. In the 80 trials were conducted in the United States and processes were started to promote this crop in the North American continent. In the 90´s trials were conducted in Denmark, the Netherlands, and Italy. Projects such as "The American and European Test of Quinoa" assessed the potential of quinoa outside the traditional areas of production in countries in North America, Europe, Africa, Asia and Australia. The following is a brief summary of the expansion and scope of quinoa cultivation outside the Andean Region.

### 7.1. North America

After trying unsuccessfully in 1979 to import quinoa to the United States, in the 80´s two trials were started in the South of the State of Colorado. The results obtained with ecotypes of the group "Costeño" led to the creation of a partnership with the producers involved with quinoa in this country and in Canada. At the same time research programs and technology development programs were developed for the whole chain by the University of Colorado (Johnson, 1990, Laguna, 2003). In 1994 genetic material called "Apelawa" essential for improvement processes was patented, but was withdrawn four years later for not representing an innovation and attempting against the Convention on Biodiversity. Until 2000, research was being carried out for the improvement of highly productive and competitive hybrids (Laguna, 2003).

In the U.S., quinoa is produced in Colorado and Nevada, and in Canada in the prairies of Ontario, with a total area of 2,300 ha (Suca Apaza and Suca Apaza, 2008). In the state of Colorado this grain is grown with average yields of 1,000 kg / ha (Jacobsen, 2003). Canadian yields are more variable but can reach 830 kg / ha (Laguna, 2003).

### 7.2. Europe

Several countries in this continent were members of the project: “Quinoa – A multipurpose crop for the EC’s agricultural diversification” adopted in 1993. Studies and introductions of quinoa genetic material were made in the 80´s and 90´s in Europe, and as a result Chilean materials of the "Costeño" group were adapted to these areas (Jacobsen, 1998). Moreover, major improvement projects have been carried out in quinoa, finally obtaining the first European quinoa variety "Carmen", a dwarf variety with compact panicle and early maturation. The work continues in order to increase yields, adjust the growth cycle and reduce the saponin content and with the generation of new varieties such as "Atlas" (Jacobsen, 2003).

### 7.3. Africa

Colombian cultivars produced high seed yields (4 t / ha) in Kenya so the crop represents an interesting alternative for reducing hunger and poverty on this continent (Jacobsen, 2003).

## 7.4. Asia

Studies in the Himalayas and the plains of Northern India have shown that the crop can successfully produce high yields in this Region (Bhargava et al., 2006). In this area, where the diet is based on rice and wheat, quinoa would be an effective alternative to combat "silent hunger" and low protein diets.

## 7.5. Areas of the world where it could be cultivated

Quinoa production is not exclusive to the Andean Region. Other mountainous Regions of the world such as the Himalayas and mountainous Regions of Africa could have an interesting potential for the diversification of the productive systems of developing countries of these Regions (Jacobsen 2003; Bhargava et al. 2006).

Tropical savanna areas of Brazil within the South American continent have experimented with the cultivation of quinoa since 1987 and have the potential to obtain higher yields than those of the Andean Region (Spehar and Souza, 1993, Spehar and Santos 2005, Spehar and Santos, 2006).

The experience of countries in North America and Europe showed an interesting potential for expansion of this crop, making use of the grain and as fodder. The extension of larger areas of cultivation could be achieved through breeding programs from adapted varieties.

Quinoa is highly attractive in different Regions of the globe; this is due to its extraordinary adaptive capacity to extreme ecological conditions.

Quinoa has low water requirements, for which it stands out as a potential alternative for arid areas of the globe. A recently concluded project sought to develop irrigation technologies[6], such as deficit irrigation in the Bolivian Altiplano, which allows the crop´s establishment and development to be guaranteed in arid zones (Garcia et al., 2011).

Moreover, as seen in previous chapters, quinoa can be grown in various soil types with a broad range of pH (4.5 to 9.5). The capacity of this plant to produce in saline areas of low fertility allows its establishment in areas unsuitable for other crops (one of the major production areas of quinoa in Bolivia borders two saline areas: the Uyuni and Coipasa salt flats). Another abiotic factor that quinoa tolerates is frost before flowering, an outstanding feature for cold Regions (Mujica and Jacobsen, 1999).

Both Bolivia and Peru apply small scale technology (compared to other agricultural activities) for the production of this crop. This again demonstrates the potential of this sector to be implemented in countries with less access to mechanical agricultural.

[6] These technologies were developed with tools such as FAO´s AQUACROP model, calibrated and validated for quinoa

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