Quinoa's Spreading at Global Level: State of the Art, Trends, and Challenges

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Abstract

Quinoa (*Chenopodium quinoa* Willd.) is a dicotyledonous herbaceous plant of the Amaranthaceae family. Its center of origin is in the Andes Region in South America. Across the region, an important biodiversity of the species has been maintained mainly for cultural reasons. The ancestral cultivation areas are found in the Southern Altiplano of Bolivia and the Puno Region in Peru, near Lake Titicaca (between 3650 and 4200 m above sea level).

Until 50 years ago, the production was exclusively located in South America. The United States started to produce in 1947, and Europe continued the expansion process in the 1970s. Since the 2000s, the cultivation of quinoa has expanded globally due to the recognition of its nutritional value and its ability to adapt to different geographic regions. Its consumption was promoted in many countries with food safety problems due to its high content of proteins, lipids, vitamins, and minerals together with an excellent balance of essential amino acids. In addition, it has the possibility of being cultivated in a wide diversity of agroecological environments, especially because it is tolerant to frost and drought and grows even in saline soils. In most countries, it is grown in small areas and with very little use of chemical inputs.

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The increase in the worldwide quinoa area is related to an increase in scientific knowledge, especially in crop agronomy for different environments. Currently, the main trend is the breeding of plant varieties adapted to specific conditions in countries with growing demand. Consumption focuses on pearlized and saponin-free grain and increasingly in processed products. A market niche for organically produced quinoa with a designation of origin is stable. The upward trend in quinoa consumption will continue in industrialized countries because it responds to a structural process associated with changes in eating habits.

Quinoa is a food of the future, not only because it is a crop to improve food security in some countries but also because of its ability to develop in regions of the world where climate change has weakened the conditions for agriculture. However, this increase in quinoa production at a global level requires efforts in protecting and preserving its biodiversity in situ in the Andean region.

Keywords

Quinoa · Agrobiodiversity · Cultivation · Trends · Global spreading · Andes · World

1.1 Introduction

Quinoa (*Chenopodium quinoa* Willd.) is an annual herbaceous plant belonging to the family Amaranthaceae, where the Chenopodioideae represents a subfamily with 26 genera. In the tribes of Atripliceae C. A. Mey. (Syn. *Chenopodieae* Dumort.), Fuentes-Bazan et al. (2012) have included here also the genus *Chenopodium* and related genera, such as *Chenopodiastrum*, *Lipandra*, and *Oxybasis*.

The species was domesticated in South America with a center of origin located near Titicaca Lake between Peru and Bolivia. Its high content of proteins, lipids, vitamins, and minerals and an excellent balance of essential amino acids (Hernández-Ledesma 2019) characterize the grain of quinoa.

The main production areas are in the Andean highlands, in the driest regions of the continent. During many years, Bolivia was the main exporter, but Peru nowadays is a strong competitor. In Bolivia, the largest areas of cultivation are concentrated in the Southern Altiplano (between 3650 and 4200 m above sea level), expanding to the Central Altiplano and other territories after the increase in demand for the grain in the three last recent decades. In Peru, quinoa crop is cultivated ancestrally in the Altiplano of the Puno Region and in recent decades with a significant growth of the surface toward the inter-Andean valleys and other zones of the country at low altitude. Like the potato tuber, quinoa crop was one of the main foods of the pre-Inca Andean peoples.

The special interest in Quinoa is favored because it is a crop with an extraordinary capacity to adapt to different geographical areas and a diversity of agroecological environments. It is a highly rustic plant with great tolerance to frost (Jacobsen et al. 2005), soil salinity (Hariadi et al. 2011), and drought (Razzaghi et al. 2011).

Consequently, regions with low food production, where soils are saline and water is scarce or of low quality, have begun cultivation with relative success in recent decades (Bazile et al. 2016b; Nanduri et al. 2019).

1.2 The Origin of Crop

Initially, the center of quinoa's genetic diversity was identified in the Southern Altiplano of Bolivia (Gandarillas 1979; Wilson 1988). In later years, Christensen et al. (2007) noted that the center of genetic diversity was located further north in the Central Altiplano area around Lake Titicaca between Peru and Bolivia at an altitude of 4000 m above sea level. These regions are mountainous and are characterized not only by high altitude but also by scarce and irregular rainfall, which means a limited agricultural productive capacity.

Molecular evidence suggests that genetic erosion—or loss of genetic diversity—was affected by at least four events (Fuentes et al. 2012). The first would have occurred in the initial polyploidization stage, when the two diploid ancestors of quinoa hybridized to generate tetraploid descendants in nature. The second occurred when quinoa was domesticated by Andean societies from its wild tetraploid relatives, in search of a plant suitable for agriculture, 7000 years ago (Bazile 2015; Jellen et al. 2015). Through long cycles of seed exchange and cultivation in new territories and climates, there was a wide range of morphological modifications, such as condensation of the inflorescence at the terminal end of the plant, increase in plant and seed size, loss of seed dispersal mechanisms, and high levels of pigmentation (Mujica et al. 2001). At this stage, quinoa became a central element of the agricultural and food systems of this region, being present in religious rituals and other daily aspects of Andean societies.

The third event of loss of genetic diversity began more than 500 years ago during the time of the Spanish conquest, when quinoa was culturally stigmatized as food for indigenous communities (Cusack 1984). European grains were imposed on colonized populations, and the food culture related to quinoa declined, considering it as food for animals and the poor. The central role of this plant within religious ceremonies and local daily life was what prevented its disappearance.

The recent history of quinoa suggests a fourth event caused by human migration from rural areas of the high Andes to urban centers and coca-growing regions of the eastern foothills, resulting in abandoned quinoa fields and loss of quinoa germplasm (Fuentes et al. 2012).

1.3 Cultivation and Expansion Worldwide

1.3.1 Quinoa's Global Spreading During the Last 30 Years

In the first stage, more than 5000 years ago, the limits of the geographical extension of quinoa were limited to only a few regions of the Andean countries. Since its domestication around Lake Titicaca, and during the course of human migrations, this was progressively adapted by farmers to other ecological and social contexts of cultivation, extending to new territories in Bolivia, Peru, Chile, Argentina, Ecuador, and Colombia along a latitudinal gradient that extends from 5°S to 30°S, although it is a truly common crop until 20°S.

Comparing the types of quinoa across the regions where it is grown allows for differentiation of ecotypes according to their agro-morphological characteristics and adaptation to the ecosystems. In this regard, Tapia (1996) was the first who proposed the differentiation of quinoa into five major groups according to their characteristics of adaptation to the different agroecological conditions in the Andes:

– The quinoa of the Northern Altiplano of Lake Titicaca (Peru and Bolivia), which has a short growth period and develops with rainfall that varies between 400 and 800 mm and minimum temperatures of 0 °C.
– The salt flats quinoa in the Southern Altiplano (Bolivia, northwest Argentina, and northern Chile), adapted to saline soils and having a larger grain size, are found in areas with less rainfall (250–400 mm) and minimum temperatures of −1 °C.
– The quinoa in the inter-Andean valleys (mainly in Peru and Ecuador), in mesothermal zones with rainfall varying between 700 and 1500 mm and minimum temperatures of 3 °C.
– Coastal or sea-level quinoa is a smaller, dark-grained plant grown in central and southern Chile with rainfall of 500–1500 mm and minimum temperatures of 5 °C.

The quinoa of the Yungas or subtropical zone, on the eastern slopes of the Andes in Bolivia, with rainfall that can reach more than 2000 mm and minimum temperatures of 11 °C.

During the second half of the twentieth century, the number of countries where quinoa is experimented or cultivated grew rapidly from the 7 that make up the Andean region (Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela) to more than 100 in different climatic zones of the planet. Today in 2020, we identified more than 125 countries at global level. This worldwide expansion presents at least two main stages.

The first includes the main consuming and importing countries—the United States, Canada, France, the United Kingdom, Denmark, and the Netherlands—which sought to adapt the crop to their environments. The United States became interested in this grain as early as 1948 and in the early 1970s conducted experiments in southern Colorado with seeds of Chilean origin (Johnson and Croissant 1985). In Canada, it is grown on the plains of Saskatchewan and Ontario, which are traditionally grassland or cereal-producing areas. In this first stage is the introduction of quinoa in Europe in 1978, also with germplasm from Chile (Universidad de Concepción in Chile) that was taken, selected, and tested in Cambridge (England) and in the Loire Valley (France) (Bazile and Baudron 2015). This Chilean germplasm plus the Andean germplasm collected in 1982 by Galwey and Risi generated the basis for the Cambridge University breeding program under the leadership of Nick Galwey (Fleming and Galwey 1995; Galwey 1989, 1993). From Cambridge, quinoa was distributed to Denmark, the Netherlands, and other European countries (Risi and Galway 1991).

A series of events spread the word about quinoa. For example, the International Board for Plant Genetic Resources, a member institution of the CGIAR (now *Bioversity International*), organized the first regional meeting on plant genetic resources of agricultural interest in the Andean Region in April 1981. Later, in 1993, a European Union project began field research with quinoa in England, Denmark, the Netherlands, and Italy, as well as laboratory tests in Scotland and France. Nevertheless, probably, the most important project in the 1990s, which explains the worldwide expansion of quinoa, is the one that started in 1996 with a shared coordination between the Danish International Development Agency (DANIDA) and the International Potato Center (CIP) in Peru. The aim of the project was to learn about the state of the art of quinoa and to carry out multiple experiments at a global level. Through this first international cooperation network, there were field trials in new countries such as Sweden, Poland, Czech Republic, Austria, Germany, Italy, and Greece (Iliadis et al. 1997). This initiative significantly increased the links between researchers and the number of research centers involved with the quinoa issue in developing and developed countries. It is from this period the research work carried out by Denmark and the Netherlands resulted in the first European variety of quinoa, Carmen, and continued with research aimed at reducing the saponin level of the grain.

The second stage of worldwide dissemination of quinoa began in recent years, where global climate changes were a reason for the advance of research in new countries. Quinoa is nowadays presented as a response to worsening environmental conditions, particularly in semiarid areas where intensive use of groundwater causes soil salinization. This is how the Asian continent enters the picture, with India and China (Bhargava et al. 2006; Xiu-shi et al. 2019) as well as Pakistan (Munir 2011). The Mediterranean region corresponds to the latest important step in the expansion of quinoa and links numerous partners from European Union countries (Italy, Portugal, the United Kingdom, the Netherlands, and Denmark) and Mediterranean countries (Turkey, Morocco, Egypt, Syria) (Benlhabib 2006; Pulvento et al. 2012).

In 2013, at the initiative of the Plurinational State of Bolivia, the International Year of Quinoa (IYQ) was celebrated with the aim of focusing world attention on the role of quinoa in food security and poverty eradication in support of the achievement of the Millennium Development Goals. The IYQ promoted awareness of the benefits and qualities of quinoa and a recognition of so-called underutilized species (NUS), which play a key role in food and health because of their high nutrient content and have characteristics that allow them to adapt to different ecological conditions (Bravo et al. 2010). The IYQ has had a positive impact, which is projected in an

Table 1.1 Number of Andean and non-Andean countries by first year of planting

First sowing date	<1935	1935–1954	1955–1974	1975–1994	1995–2012	2013–hoy
Andean countries	6	6	6	6	7	7
Outside Andes	0	2	2	13	38	118

Source. Adapted from Bazile et al. (2016a)

increase of research in numerous institutions around the world, in an extension of the areas of cultivation, and in an increase in consumption, especially in the United States, Europe, China, and India. The appearance on the market of numerous innovative products containing quinoa is one of the impacts of the IYQ, with the possibility that quinoa will become a food of the future.

Between 2013 and 2015, new countries received technical assistance from the FAO as part of the strategy to strengthen global food security through the cultivation of quinoa. Further, 26 countries benefited from 6 regional or local projects (Algeria, Egypt, Iraq, Iran, Mauritania, Sudan and Yemen/Djibouti, Ethiopia, Kenya, Somalia, Southern Sudan, Uganda and Zambia/Burkina Faso, Cameroon, Niger, Senegal, Chad, Guinea and Togo/Sri Lanka and Bhutan/Kyrgyzstan and Tajikistan/Morocco).

The following table lists the number of Andean and non-Andean countries by first year of planting (Table 1.1).

1.3.2 Current Status of the Production in Bolivia and Peru: The Two Main Producers at Global Level

Bolivia and Peru are the world's leading producers of quinoa. It is estimated that there are about 70,000 quinoa producers in Bolivia and another 60,000 in Peru, with production predominantly at the household level.

Peru, unlike Bolivia, decreased the areas of quinoa cultivation gradually in recent centuries after the appearance of new foods brought with the Spanish colony. However, it was maintained continuously in the Puno Altiplano in the ancestral systems or aynokas, in rotation with other crops, and preserved the quinoa and its wild relatives because of its nutritional, medicinal, and religious value (Mujica and Jacobsen 1988; Aguilar and Jacobsen 2006; Mujica 2008, 2011; Gómez Pando et al. 2014). It was also possible to find it in the inter-Andean valleys, where quinoa is planted in association with corn, beans, broad beans, and cucurbits. Although production in these areas used to be important, it was not sufficient to satisfy domestic demand, and, for this reason, Peru was for several decades the main buyer of Bolivian quinoa (Aroni et al. 2009). Currently, it has doubled the area with quinoa, reaching almost 70,000 ha by 2018.

In Bolivia, the area of quinoa remained stable over time. In the Southern Altiplano, the country's most traditional production area, it was planted on the mountain slopes so that it would be less exposed to night frost, and the plains were used for grazing llamas and sheep, which are more resistant to the cold than crops (Pouteau et al. 2011). After the first quinoa boom of the 1980s, this was changed, and cultivation expanded with the introduction of machinery (Martz 2016; Kerssen 2015).

In both countries, the highest sales flows are recorded in the harvest months. However, due to fractional selling strategies, a part of the production reaches the market throughout the year. In general, producers in Peru and Bolivia sell quinoa at weekly fairs, and in some areas, the practice of barter is still alive, where the unit of measurement is the handful and it is exchanged for vegetables or bread. In these markets, quinoa is not standardized and farmers sell a favorable mix of quinoa varieties. Quinoa wholesalers, who handle large volumes and supply urban markets and agro-industries, meet at local fairs or larger markets, such as the Challapata fair in Bolivia or the Manco Capac market in Juliaca, Peru. These intermediaries buy at the weekly fairs or directly from the communities and, as in many other food chains, have some power in the negotiations.

In the 1990s, the certification of biological agriculture brought added value to this grain, and, more recently, the networks of the fair trade added an ethnic image to the product on the markets. These two processes allowed a better remuneration of the producers and at the same time signified a commitment of the consumer with the agroecological practices of the production.

Depending on the destination, a dichotomy of varieties between registered/ improved and traditional varieties is maintained. However, with the recent boom in urban and international demand, agro-industries and exporters are trying to meet the demands of markets that generally require uniform and large grains. This encourages producers to plant certain improved varieties, and this may represent a risk to biodiversity if all export production follows this standardization dynamic.

In Bolivia, the most important production is the *quinoa real* of the Southern Altiplano (Departments of Oruro and Potosi). In its expansion and improvement of commercialization, the presence of the economic farmers' organizations has been fundamental, such as the *Central de Cooperativas Operación Tierra* (CECAOT) and the Bolivian National Association of Quinoa Producers (ANAPQUI), with the support of the *Confederación Sindical Única de Trabajadores Campesinos de Bolivia* (CSUTCB).

In Peru, the export boom began later in 2005 with the production of individual quinoa farmers who do not necessarily belong to a cooperative or association, as it is mainly the case in Bolivia. Faced with the commercial development of quinoa in nontraditional areas and abroad, Andean producers have initiated new ways of valorizing and protecting their products, such as the recognition of denominations of origin and solidarity trade. The diversity of original products, quality seals, alliances, and innovative institutional practices demonstrate the capacity for innovation of producers and the different actors in the quinoa value chain.

The destination markets for regional quinoa exports have changed in the last decade, both because of the emergence of new consumers and the new organization of existing ones. The United States has increased its importance as a destination market, accounting for 56% of imports from Bolivia, Ecuador, and Peru. Due to the entry of new consumer countries in recent years, the European markets of Germany, France, and the Netherlands along with Japan were losing weight (in percentage) as purchasing countries. Although this occurs in the context of a general increase in the volume traded in the international market, in absolute terms, exports to Europe, especially, have also increased significantly even if the European production is always increasing year after year in different countries.

1.3.3 Current Outlook

For 20 years, Andean quinoa has been a highly dynamic product in world trade. Its consumption has increased globally, especially in the United States, Europe, China, and India. There are several reasons that explain the process, including the high nutritional quality of the grain, the propensity toward healthy eating patterns, the revaluation of ancestral cultures, and the fact that it is a product originated in small peasant farms and the mostly organic condition of the supply.

The "boom" of quinoa had its origin in the demand from North American and European countries for foods with specific dietary qualities and with an ecological origin. The growth of the markets for organic, natural, and family farming products is due to changes in consumption habits and to evidence linking the consumption of refined and ultra-processed foods with "modern" diseases such as diabetes, allergies, obesity, and cardiovascular diseases. This boom meant an increase in regional quinoa exports, with strong and sustained growth from the 1990s onward and an even greater boom since 2000.

Since 2012, there has been an increase in the area of production in the Andean countries and in the rest of the world. For example, Greece, India, Italy, Morocco, and Turkey have gone from having areas of less than 100 ha to crops of between 100 and 500 ha (only 5 years after the IYQ), and China has already reached 17,000 ha (2019) (Xiu-shi et al. 2019). Bolivia and Peru continued to increase the area of quinoa production after the IYQ, reaching maximum areas in Peru in 2018 and Bolivia in 2015, with 67,000 ha and 121,000 ha, respectively (FAO STAT 2020).

Quinoa production systems at the global level are generally characterized by small areas of cultivation (with an average of 2 ha), and, in general, the increase in the area of Quinoa at the global level is directly related to the increase in the number of farmers, both in the new producing countries and in those that started cultivation before the twenty-first century. Canada, France, and Turkey, which in 2012 had less than 100 producers, have moved to the stratum of 101–500 producers in 2018. Other examples are China and Colombia, which increased their number of producers to more than 1000 (5 years after IYQ). In the new producing countries, quinoa is added mostly as a crop for the diversification of production systems and in some cases as a replacement for another crop, which can be explained as an adaptation strategy for agriculture in these countries to the strong effects of climate change.

In these years, there have been significant advances in agricultural research with the development of new improved varieties and innovations for postharvest tasks and the industrialization of the grain. The appearance on the market of many products containing quinoa after 2013 gives the prospect that this will become a food of the future, both for its high nutritional value and for its great genetic diversity that allows it to adapt to different agroecological conditions. However, this increase in quinoa production and consumption requires the protection and conservation of existing genetic biodiversity in situ in the Andes region and the need for specific mechanisms.

1.3.4 Who Is Doing Quinoa Research?

Universities and research centers are the main institutions related to quinoa expansion in new areas of production at the global level. There are mainly government research centers dedicated to genetic improvement and crop adaptation to new environments. Private companies and producer organizations are most linked to experiments with postharvest technology. In some areas, there are some key farmers dedicated to the improvement of the crop value chain from the seed selection stage to the search for alternatives to process quinoa.

For facilitating the dissemination of research results for sharing experiences, there are networks of experts made up of members of research centers and universities, local government staff, and farmers. In some cases, expertise is found in international agencies such as the FAO, and these people have to be connected with these scientific networks like the Global Collaborative Network on Quinoa (gcn-quinoa.org).

In the case of the Andean region, national and local governments are the other important participants in the promotion and research processes as well as several Non-Governmental Organizations (NGOs) and producer organizations. Farmers' organizations and NGOs were the first to develop the quinoa value chains in Bolivia during the 1980s and the 1990s, when government services appeared during the past 20 years, considering the importance of quinoa as an export product for the commercial balance of the country. It was the same in Peru with important programs managed by the two ministries of agriculture and economy, which are involved for supporting the development of the Peruvian quinoa value chain for the export markets.

After the IYQ in 2013, there was a real boost to quinoa in the Andean countries through the implementation of public policies toward the sector, with government investment in technological innovations and support to networks of experts and institutions for the improvement of quinoa production and commercialization, with emphasis on the sustainability of the crop. The main public policy of these countries is technical assistance to peasant family agriculture from both national and local governments, especially in areas where landowners had migrated and returned to their communities to cultivate the land.

As a result of the IYQ, the International Quinoa Centre (CIQ, *Centro Internacional de la Quinoa* in Spanish) was established in August 2013 with headquarters in Oruro, Bolivia. Its objective is to develop scientific and applied research on quinoa and related species and to implement appropriate technology to increase yield and sustainable production. Among its current activities is the systematization of local knowledge and know-how to face the extreme phenomena of climate change and the elaboration of resilience studies of production systems, with emphasis on the existing ancestral knowledge in the Central Highlands of Bolivia.

In the process of expanding sustainable quinoa production globally, the Global Collaboration Network on Quinoa (GCN-Quinoa) was established in 2015. This network seeks to create a collaborative space that facilitates exchanges between producers, processors, distributors, politicians, and all those involved in the development of quinoa at the global level. The main challenge of GCN-Quinoa is participatory plant-breeding program, where researchers and producers share knowledge of field experimentation in a diversity of agronomic systems and in a wide range of physical and environmental environments. It is currently made up of 300 researchers from 75 countries; Dr. Didier Bazile at CIRAD (France), the founder, assumes the facilitation.

1.3.5 Research Topics

The main research topic in the different countries is the adaptation of quinoa to new environments, and in the countries with more experience with the crop, there are today programs of genetic improvement. For example, China has had a breeding program since (1984), and this can be seen today in 18 certified varieties released (Xiu-shi et al. 2019; Guiying 2020). In the Netherlands, Wageningen University & Research (WUR) has developed sweet and short-cycle varieties adapted to European conditions. In Denmark, three varieties (Vikinga, Puno, and Titicaca) are registered, marketed, and disseminated at global level with good results in crop adaptation. In these two countries, the varieties are disseminated through the European catalogue and with the prerogatives of the Union for the Protection of New Varieties of Plants (UPOV) system. In the United States, several groups of researchers are dedicated to the breeding of quinoa varieties: currently, the Wild Garden Seed and Washington State University (WSU) companies have new materials in development, and the varieties can be shared through the seed network under open access (Open Seed Source Initiatives) (Chevarria-Lazo et al. 2015; Luby et al. 2016).

The planting of quinoa outside the Andean region faces difficulties for its production, such as heat during the flowering period that leads to irreversible stress (Hinojosa et al. 2019). The countries of the Mediterranean and the Middle East are very sensitive to this problem of temperature especially for cultivating quinoa as an alternative crop in marginal environments (Bazile et al. 2016b). In some cases, they are looking for alternative planting dates or new varieties that are more tolerant to high temperatures and drought, in addition to salinity stress (Rezzouk et al. 2020). Considering the high constraints increasing due to the effects of climate change, there are a number of new producing countries (Egypt, the United Arab Emirates, Iran, Kenya, Lebanon, Malawi, Morocco, etc.) that are working on the development of quinoa varieties adapted to the extreme environmental conditions of their countries. This pathway in quinoa research will guide the next decade for new investigations.

1.4 Trends and Consequences

The global interest during the past 5 years after the IYQ shows four main trends for the next future. First, the expansion of cultivation areas outside the Andean region will increase with some new country producers able to produce enough for putting new volumes into the international market. Second, and for the moment, the global production is always in the hands of a greater number of producers, generally planting small areas and with family farming characteristics and practices. Third, the constant increase in global consumption, especially in Europe and the United States, will benefit the Andean countries because they will continue to be attracted to quinoa associated with cultural values and derived from organic and agroecological production. More of their trade links will be established over time with local organizations under fair trade agreements and mechanisms that will be maintained. Fourth, the increase in cultivation at global level is ongoing with an increase in scientific knowledge. The novelty of this new research is that it is developed and centered on environmental conditions and social and political issues, which are not linked to the Andean context.

The outlook for increased demand in the coming years continues to be favorable because it responds to processes of a more structural nature associated with trends and more general changes in consumption patterns for natural products at global level. These changes increasingly favor foods that have healthy nutritional characteristics and offer guarantees of health and safety. They are often linked to certain special nutritional characteristics (proteins, minerals, etc.), such as the fact that they are organic products or the expression of cultural traditions of recognized value.

The growth in the production and consumption of currently has many scientific institutions dedicated to basic and applied research at the global level. There is a clear interest in promoting and funding research from national governments, both in the Andean countries and in those with food insecurity or problems due to lack of productive land for other crops.

With the exception of areas where quinoa was seeded in large areas with commercial varieties and intensively in Peru and Bolivia, there are no significant changes in production systems between 2012 and 2018. In general, quinoa is produced on small plots in the new producer countries and with low use of agrochemicals and other inputs. The use of irrigation in the new producer countries and in the Andean countries that have intensified their agriculture appears to be the main innovation for ensuring the production in arid areas. In those countries, no conventional water and deficit hydric irrigation are two ways for adapting quinoa in these areas with water scarcity.

The main trend in the last 5 years is certainly the use of improved varieties. This is happening especially in the new producer countries because they have a very limited access to the Andean genetic diversity of quinoa for cultivation. However, it is also a current trend in the Andean countries that have expanded their area and in production systems with more entrepreneurial characteristics. These agricultural systems with improved varieties have higher production costs.

To accompany the feasibility of these systems, they are looking for adding value to the quinoa grains, and consumption of processed quinoa has grown globally. The same may occur with other more specific uses, such as quinoa starch, quinoa flour, or quinoa in the form of milk. Many of these products currently have specific market "niches" in Europe and the United States, but it is likely that the consumption of "processed quinoa" will become more widespread in the coming years.

The IYQ has made quinoa in all its forms more accessible, both to people in the Andean region and to countries with food security problems. Five years after the IYQ, quinoa crop offers the opportunity to maintain and expand the spread and sustain its expansion dynamic. That is because quinoa could become one major food of the future, both because of its great genetic diversity that allows it to adapt to different agroecological conditions and because of its high nutritional value. However, this increase in quinoa production at the global level requires the protection and conservation of existing genetic biodiversity in situ in the Andean region, both of native cultivars (landraces) and of their crop wild relatives. Plant genetic resources have great value for the adaptive evolution of quinoa to different environments, where this crop is a priority for solving food security problems such as those triggered by climate change.

Certification of organic agriculture related to fair trade markets allowed a better remuneration of the producers, and at the same time, it means a commitment of the consumer with the agroecological practices of the production. However, if the crop continues to spread, there will be a need for international recognition of the Andean identity of quinoa's genetic resources and of the contribution of the peoples of the Andes to the conservation of their biological diversity and to the contribution of knowledge to its production.

Thinking globally about the sustainable use of quinoa biodiversity could facilitate a paradigm shift in agricultural models, taking more account of nutrition as an approach to agricultural development. Linking food security to the use of water and energy in agriculture, to aspects of health for farmers and consumers, and to the protection of biodiversity in agroecosystems for adaptation to climate change is probably the key for tomorrow agriculture where quinoa is a model crop (See Bazile 2020, Chapter 5).

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